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AMERICAN JOURNAL OF SCIENCE

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THE PALEOZOIC STRATA OF THE BARABOO AREA, WISCONSIN.

J. M. WANENMACHER, W. H. TWENHOFEL AND G. O. RAASCH.

INTRODUCTION.

The Baraboo area of Wisconsin, an inlier of Pre-Cambrian rocks in the midst of lower Paleozoic strata, has long been known to geologists. It is annually visited by hundreds of students from upper Mississippi Valley universities, and several of these conduct field courses there. Despite these facts, the Paleozoic strata in and surrounding the area are known in only a very general way, and little or no detail has been published with respect to them. At the suggestion of Professor Twenhofel, Doctor Wanenmacher made a detailed study of the Paleozoic section of this area, and, in addition, determined the minerals of the Pre-Cambrian rocks to learn the extent of contributions from these to the Paleozoic sediments. Parts of the spring, summer, and autumn of 1931 were given to field studies, and occasional visits to the area were made during the spring of 1932. Mr. Raasch identified the fossils and assisted in the correlation. Professor Twenhofel checked the field studies and aided through information and views developed on visits to the area extending over a period of seventeen years.

GENERAL GEOLOGICAL HISTORY.

The rocks of the Baraboo area belong to Archeozoic, Proterozoic, and Paleozoic systems. The Archeozoic rocks consist of acidic flows and acidic and intermediate intrusives. The unconformably overlying Proterozoic strata belong to the Huronian system, and from the base upward consist of the Baraboo quartzite, about 3500 feet thick; the Seely slate, 500 to 1000 feet thick; and the Freedom formation, composed of iron ore, dolomite, and chert, with a reported thickness of about 1000 feet. Drill records show that over the eastern part of the Baraboo Basin the Freedom formation is overlain by

quartzite and this in turn by red slate, each in small thickness. Only the Baraboo quartzite is exposed.

The Proterozoic strata were folded prior to the deposition of the Cambrian, the folds running east-west. Subsequent Pre-Cambrian erosion reduced the folds, and in the Baraboo area only a canoe-shaped syncline is known of the several synclines and anticlines which at one time must have been present in central Wisconsin. This syncline is exposed over an area about twenty miles long in the east-west direction and four to five miles wide in the north-south direction. The axial plane of the syncline slopes to the north so that the beds on the south side dip around 12 degrees to the north, whereas those on the north have nearly vertical attitude and in some places are overturned.

At the beginning of the Upper Cambrian, the Baraboo quartzite formed an elliptical ridge around an interior lower area. Gaps existed in the ridge, and in some places it was not high, this being particularly the case on the north side where the vertical position of the strata resulted in a much narrower ridge than on the south. Some of the quartzite hills are estimated to have risen above the surrounding area to a height of about one thousand feet.

In late Cambrian time the Baraboo area was submerged two or more times. There seem to have been three submergences during the Ordovician; there was submergence during the Silurian and, perhaps, during the Devonian. During the Upper Cambrian submergences the quartzite ridge rose above the waters of the sea as a ring of islands. The islands on the south side of the ring were long and about a mile wide; those of the north side were mostly short and narrow. This ring of islands functioned in the Cambrian seas somewhat as an atoll. The waters within were protected whereas those without were exposed to the full sweep of the waves and currents. At times the surrounding seas were shallow and the waves and currents weak; at other times the waves possessed great power; but at all times the waters within the basin seem to have been relatively quiet. A somewhat similar state of affairs prevailed during the early and, perhaps, early-middle Ordovician. By the late-middle and the late Ordovician the quartzite ridge was almost completely submerged and largely buried beneath sediments. The ridge certainly disappeared beneath Silurian waters and Silurian sediments, and if Devonian waters reached the Baraboo area they probably encountered no trace of it.

This ring of islands in the Cambrian seas had great influence upon the nature of the sediments deposited in its vicinity and particularly upon those deposited within the central area. A varied environment existed which had its effect on the organisms living about the islands.

The strata deposited about the islands received inclinations away therefrom in harmony with increase of depth outward. These inclinations range from nearly horizontal to 15 or more degrees, and steep dips are common. The steep dips persist for some distance from the quartzite ridges and seem to indicate considerable deepening of water within a short distance from the shores. The extent of the initial dip is shown in Figure 1 which is drawn on the top of the Franconia formation. Parts of the deposition areas about the ridges were probably out of water at times.

Following the last submergence the Baraboo area became land and was subjected to erosion, this beginning not later than the close of the Devonian. The Pre-Pleistocene erosion exhumed the quartzite ridges and removed large parts of the Paleozoic strata around and within them. The area within the ridges was thus reduced in elevation to form the lowland known as the Baraboo Basin. The Green Bay lobe of the Wisconsin Ice sheet advanced to a little west of the town of Baraboo, built its terminal moraine from north to south across the Basin, more or less covered the area to the east of the moraine with glacial till, and developed an extensive lake to the west.

MINERALS OF THE PRE-CAMBRIAN ROCKS.

In order to determine the extent to which the known Pre-Cambrian rocks of the Baraboo area made contributions to the Paleozoic sediments, Doctor Wanenmacher made careful studies of the mineral suites of these rocks and thus supplemented the work previously done by Doctor Hans Becker.[1] As the Baraboo quartzite is the most extensive and important of the Pre-Cambrian formations and covers the greatest areas, it was assumed to have constituted the greatest source for materials. Consequently it received the most attention.

The mineral particles of the Baraboo quartzite are domi-

[1] Becker, H., A study of the heavy minerals of the Pre-Cambrian and Paleozoic rocks of the Baraboo Range, Wisconsin, Jour. Sed. Pet., 1, pp. 91-95, 1931.

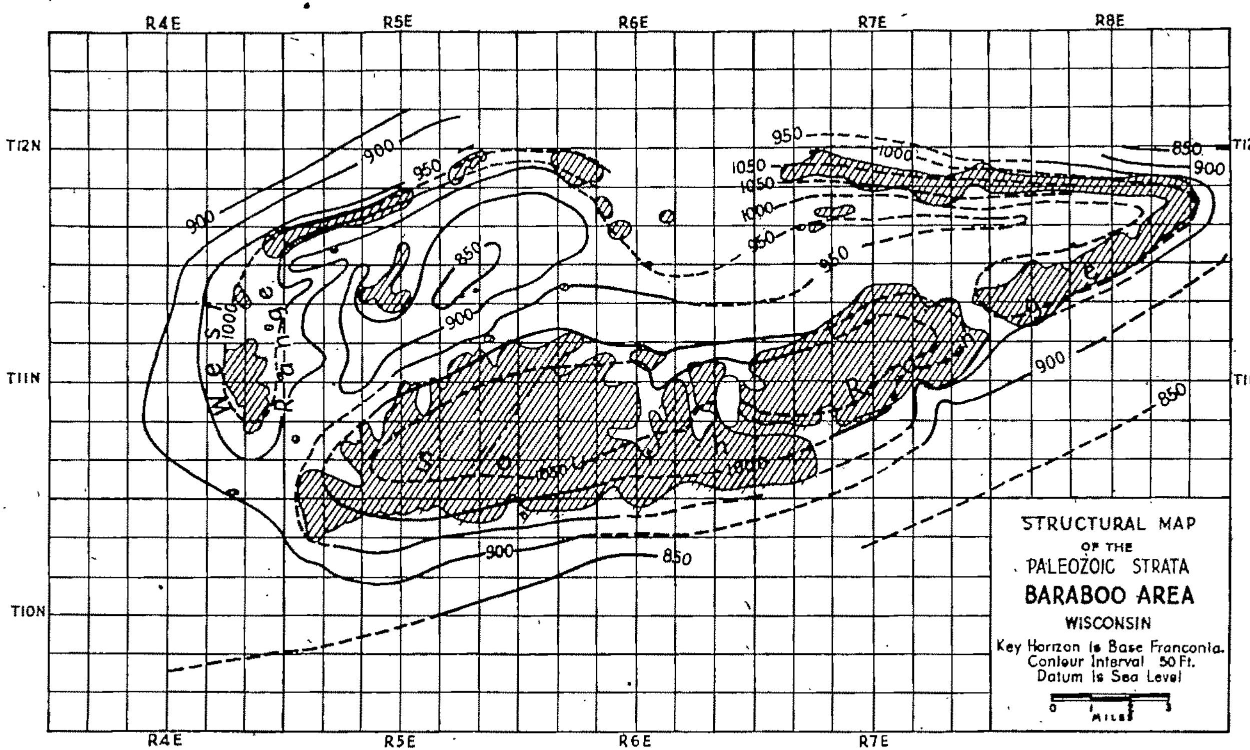


Fig. 1. Structural Map of the Baraboo Area. By J. M. Wanenmacher.

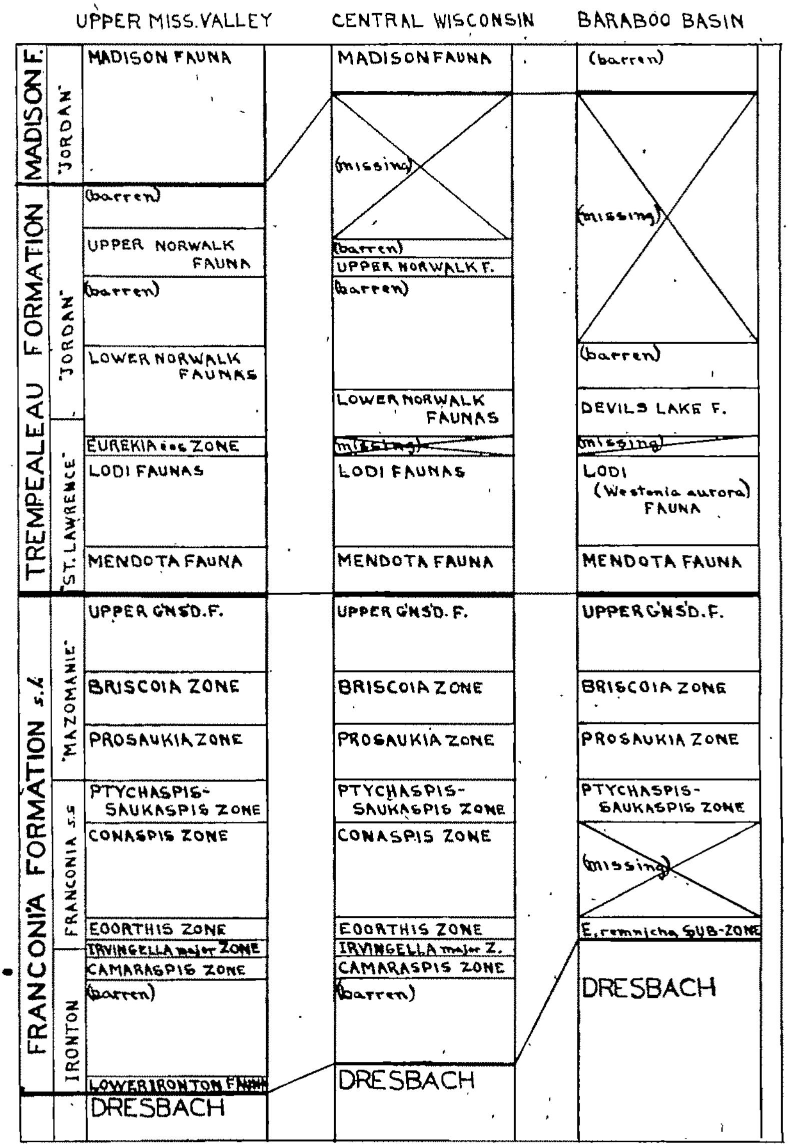
nantly quartz sands around each of which there may be a very thin film of iron oxide. Feldspar is almost entirely wanting, thus pointing to an extremely long history for these sands since detachment from the original parent rocks. The quantity of heavy minerals is very small. They consist largely of zircon, of which most are clouded yellow to yellowish-brown by zonal growth. The majority are rounded, but some of the clouded individuals are euhedral or almost so. Red-brown rutile is present in very small quantities in some samples. Other minerals are extremely rare. Those identified are tremolite (2),[2] muscovite (1), garnet (1), staurolite (1), hornblende (1), corundum (3), topaz (1), biotite (1), and barite (1). Minerals almost always present in very small quantities are magnetite, specularite, hematite, galena, sphalerite, and pyrite. The important facts with respect to the heavy minerals are the almost total absence of garnet, total absence of tourmaline, rarity of titanium minerals, and the clouded character of the zircon. The Seeley and Freedom formations are not exposed, and a thorough sampling was not possible. Material collected from mine dumps showed nothing diagnostic, and no garnet or tourmaline was found. The igneous rocks beneath the Baraboo quartzite yielded magnetite, hematite, galena, pyrite, zircon, garnet, chlorite, hornblende, biotite, apatite, epidote, fluorite, and hypersthene. The zircons are generally zonally clouded and have yellow to yellow-brown colors, as do those in the Baraboo quartzite. None of these minerals is common, and most are present in only a part of the samples.

THE PALEOZOIC STRATA.

The Cambrian and Ordovician systems are well represented over and around the Baraboo area. Evidence for the former presence of the Silurian is limited to fossils found in stream gravels on top of the ridge of Baraboo quartzite on the east side of Devils Lake and to the occurrence of Silurian strata twenty miles to the south on the top of Blue Mound at an elevation higher than any elevation in the Baraboo area. The sections which follow give details of the Paleozoic strata at their different localities.

[2] The figure indicates the number of samples in which the mineral was found.

Post-DRESBACH UPPER CAMBRIAN Succession of major faunal units in maximum thickness.



Drawn approximately to scale -

Section Exposed in Fox Glen.

Franconia.	
Firm conglomeratic sandstone	3.0 feet
Quartzitic fine- to medium-grained white sandstone containing worm burrows and fossils	13.0 "
Fine- to medium-grained yellow and yellowish-brown sandstone with beds of quartzite pebbles at intervals. The basal beds are glauconitic and dolomitic. Fossils occur horizonally	88.0 "
Interbedded greensand and red and green slightly micaceous shales. The shales are fossiliferous	4.5 "
Coarse-grained, well sorted, red to brown sandstone with clay streaks. The top foot is conglomeratic. Fossils are sparingly present. It is suggested that this is the top part of the Ironton member	3.5 "
Coarse-grained, evenly bedded, steeply cross-laminated white sandstone containing some quartzite pebbles and sparse fossils	5.0 "
Poorly sorted, gently cross-laminated white sandstone with laminæ of green clay and scattered pebbles of quartzite and white quartz	10.0 "
Conglomerate of quartzite pebbles in matrix of sand	1.5 "
Medium-grained sandstone with pebbles of quartzite	1.5 "
Dresbach.	
Massively to poorly bedded, poorly cemented, medium-grained yellow sandstone. The top foot has clay streaks	4.5 "
Total thickness	134.5 feet

Section Exposed in Quarries Near Denzer.

Sec. 14, T. 10 N., R. 5 E.

Oneota.	
Hard, evenly bedded, finely crystalline, gray to buff dolomite containing seams and pockets of green clay and numerous small vugs	30.0 feet
Soft, fine-grained well sorted white sandstone	2.5 "
Seam of green clay	0.1 "
Sandy, impure dolomite	1.0 "
Fine-grained, ripple marked white sandstone	4.5 "
White to buff sandy shale and green clay shale	1.0 "
Madison?	
Dense, hard, evenly bedded, yellowish-gray sandy dolomite. Contains occasional pebbles and granules of quartzite	8.0 "
Concealed.	
Probably Norwalk (Jordan) member of the Trempealeau	43.0 "
Trempealeau.	
Medium- to coarse-grained brown sandstone	1.3 "
Very thin-bedded tan to buff impure and sandy dolomite. Contains a bed of silty gray shale	12.0 "
Hard, evenly bedded, impure buff dolomite. Bedding planes 3 to 6 inches apart	11.0 "
Fine-grained brown sandstone	1.0 "
Hard buff dolomite	0.9 "
Sandy glauconitic dolomite	3.0 "

Franconia.	
Concealed ....More than	100 feet
Fine- to medium-grained, evenly bedded, cross-laminated dolomitic sandstone..	3.0 "
Coarse-grained sandstone containing abundant pebbles and granules of quartzite..	3.0 "
Fine- to medium-grained, well sorted dolomitic and glauconitic sandstone. Contains lenses of clay and pebbles of sandy dolomite. Some of the upper layers are mud cracked......	8.0 "
Interbedded coarsely crystalline red dolomite, finely crystalline yellow dolomite, and coarse greensand. Dolomite contains fossils	2.0 "
Poorly sorted sand and quartzite granules and pebbles from underlying sandstone	0.8 "
Dresbach.	
Medium- to coarse-grained, poorly sorted sugary white sandstone. Contains seams of greenish clay and pebbles of quartzite.	9.0 "
Total thickness	251.1 feet

SECTION EXPOSED ON HIGHWAY 136.

SE ¼ NE ¼ Sec. 13 and NW ¼ Sec. 12, T. 19 N., R. 4 E.

Oneota.	
Thin-bedded, finely crystalline gray dolomite of which basal 3 feet are sandy..	6.0 feet
Madison.	
Fine-grained, quartzitic white sandstone........................	4.0 "
Coarse-grained, poorly sorted light to dirty brown sandstone..	5.0 "
Trempealeau.	
Interbedded fine- to coarse-grained sandstones and sandy shales. The sandstones range in color from brown to gray and are friable. The shales constitute about one-fourth and range from clay to silt and the tops of the shale beds have mud cracks.	14.0 "
Concealed.	6.0 "
Fine- to medium-grained buff to white sandstone. Cementation is poor and the exposure is not good. Small worm burrows are present..	10.0 "
Concealed.	29.5 "
Thinly bedded buff dolomite with green clay partings on some bedding planes. Not well exposed........................	19.0 "
Medium- to coarse-grained brown sandstone containing quartz and quartzite granules..................................	4.5 "
Franconia.	
Poorly exposed sandy and clay shale........................	3.0 "
Very glauconitic, poorly sorted brown sandstone	3.0 "
Concealed.	18.0 "
Fine- to medium-grained well-sorted, cross-laminated brown to gray sandstone..	11.5 "
Conglomeratic and dolomitic sandstone. Contains numerous quartzite pebbles and cobbles..................................	6.0 "
Gray to light brown glauconitic and dolomitic sandstone with pebbles and cobbles of quartzite..........................	8.0 "
Concealed.	19.0 "

Coarse- to medium-grained, cross-laminated dolomitic buff sandstone containing abundant granules and small pebbles of red quartzite and a few green quartzite pebbles	7.5 feet
Concealed	11.0 "
Medium-grained, cross-laminated gray to buff sandstone with a one-inch seam of buff shale in the middle	6.0 "
Fine- to medium-grained, glauconitic brown sandstone with a thin seam of green shale at the top	7.0 "
Dresbach.	
Medium- to coarse-grained, cross-laminated brown to gray sandstone	34.0 "
Total thickness	232 feet

THE CAMBRIAN PERIOD AND SYSTEM.

The Cambrian system is represented over and around the Baraboo area by the Dresbach, Franconia, Trempealeau, and Madison formations. All are dominantly sandstones, with dolomite and silt members intercalated in the Franconia and Trempealeau formations. Adjacent to the quartzite ridges, moreover, each formation contains a greater or less quantity of quartzite fragments. There is much local variation in the degree of induration of the sandstones. The chart which follows gives the Cambrian faunal succession for the upper Mississippi Valley, central Wisconsin, and the Baraboo Basin.

DRESBACH FORMATION.

General Considerations.

L. C. Wooster[3] proposed the term Eau Claire in 1882 for fossiliferous, thin-bedded, silty sandstones and for the coarser unfossiliferous sandstones that underlie them. The term Dresbach was first applied in 1886 by N. H. Winchell[4] to gray, micaceous, fossiliferous sandstones now known to be in part contemporaneous with and in part slightly younger than the "Eau Claire Trilobite Beds" of Wooster. Thus the terms are more or less synonymous, with the former having priority. The coarse unfossiliferous sandstones below the "Eau Claire Trilobite Beds," designated the "Eau Claire Grits" by Wooster, were named the Mt. Simon formation by Ulrich

[3] Wooster, L. C., Geol. of Wisconsin, Vol. IV, pp. 109-110 and 116-117, 1882.

[4] Winchell, N. H., 14th Ann. Rept. Geol. and Nat. Hist. Surv. Minnesota, pp. 334-336, 1885.

who also restricted the name Dresbach to the unfossiliferous sandstone above the "Eau Claire Trilobite Beds" and limited the term Eau Claire to the fossiliferous strata. The differentiation of these three units into three formations is extremely questionable as all are composed of sandstone, and no unconformity has been demonstrated to be present in the sequence. The writers incline to the view that there is only a single formation which they propose to designate the Dresbach. This formation from the base upward would then be composed of the Mt. Simon sandstone, the Eau Claire silty sandstone, and the topmost sandstone. The middle fossiliferous member thins to eastward from the Mississippi River and disappears before reaching central Wisconsin. It is not known to be present in the Baraboo area.

The Dresbach sandstones are exposed in considerable detail on both the inner and outer sides of the quartzite ridges and also over many parts of the surrounding region. Good exposures may be seen in Fox Glen, Narrows Creek, Skillet Falls, Ableman Gorge, and at numerous points to the south of the ranges. The maximum exposed thickness, about 75 feet, may be seen in Ableman Gorge.

Locally the Dresbach sandstones are well cemented, as is the case on the south end of the Ableman Gorge, where quarries have been operated in these rocks for many years. At other places, particularly outside of, and away from, the quartzite ridges, the cementation is generally poor. Case-hardening is common and may give the impression of greater firmness than is the case. Colors range from pure white and light gray to shades of yellow, brown, and, more rarely, red. The grain size varies with locality and horizon, and the upper beds are generally finer-grained than the lower. Grains whose dimensions exceed one-half millimeter are prevailingly well-rounded, but with decrease in dimension greater angularity obtains. Sorting tends to be good except very close to the quartzite ridges where quartzite fragments may be included.

Bedding planes in the Dresbach are generally widely spaced and poorly defined. Cross-lamination is very common, and in some places it is on a large scale with foresets of vertical dimensions of six to eight feet and horizontal dimensions two to three times as great. Such large scale cross-lamination seems to be more common in the higher beds, and in places it exists in immediate contact with quartzite cliffs, as may be seen in the high cliff on the north end of Ableman

Gorge, where also the cross-laminated units have the wedge shapes characteristic of eolian deposition. The directions of inclination of cross-lamination near the quartzite ridges are rather consistently away therefrom.

No fossils have been found in the Dresbach sandstone of the Baraboo area. Causes for the absence are not known.

Minerals of the Dresbach Sandstone.

The sands composing the Dresbach consist almost entirely of quartz of which many particles are enlarged. Rare grains have inclusions of tourmaline, apatite, and rutile. There is no dolomite. The heavy minerals are in small quantity, and the most abundant is zircon of which the particles are round and, for the most part, clear. Colorless to light pink garnet is present in some samples. A few samples contain pink to red garnet, and an emerald green particle was seen in one sample. The mineral is usually very rare in the lower beds, but becomes moderately common towards the top where it may approximate equality with zircon. Brown tourmaline is present in small quantity in about half the samples. Ilmenite, or its decomposition product, leucoxene, occurs in a few grains in practically all samples, and secondary hematite is prominent in some. Extremely rare minerals, absent in most samples, are rutile, galena, and tremolite. The only noteworthy difference in the distribution of the heavy minerals is the increase in garnet toward the top. Compared with the succeeding Franconia formation the Dresbach shows a total absence of glauconite and a rarity of garnet.

The heavy minerals of the Dresbach differ from those of the local Pre-Cambrian rocks in containing garnet, tourmaline, both essentially absent in the Baraboo Pre-Cambrian, and clear and transparent zircon, whereas the zircon in the local Pre-Cambrian is yellow to yellowish-brown and zonally clouded.

Environment of Deposition of the Dresbach Sediments.

The environment of the deposition of the Dresbach sediments is by no means clear. The absence of fossils points to an environment in which organisms with preservable parts probably did not live, as there is nothing to indicate that they

were ever present. The inability to live over the areas of the Dresbach deposition may have been due to extreme shallowness of water, to frequent exposure of the bottom, to rapid changes in saltiness of the water, or the water may have been fresh. The upper Mississippi Valley region at that time was an interior region, and the quantity of fresh water supplied to the areas of Dresbach deposition may have been so great as to keep out salt water most of the time. The cross-lamination gives some support to the view that parts of the sands accumulated under subaërial conditions. At several places closely adjacent to the quartzite cliffs there is very high angle cross-lamination with foresets of six to eight feet in the vertical component and more than twice that distance in the horizontal. Some such occurrences are exposed within twenty feet of cliffs of quartzite which are margined by abundant angular talus. A fact of importance in connection with such large scale cross-lamination is the absence of conglomerate spread out from the cliffs, in spite of the fact that there was much talus material. If this high angle and large scale cross-lamination had been made by water currents there must have been water with depth approximating the vertical components of the cross-lamination, and waters so deep would have had sufficient power to have strongly beaten and eroded the cliffs and talus and to have dragged gravels many feet outward from the shore. But this was not done, and sand was merely sifted among the blocks of quartzite talus. Strong waves and currents can hardly be postulated, but if the large scale cross-lamination is of aqueous origin strong currents and waves must have existed. The alternative is that the large scale cross-lamination at the feet of the quartzite cliffs with no accompanying gravel was produced by wind, with which view the wedge shapes of the cross-laminated units harmonize. Such large scale cross-lamination could readily be built by wind against the quartzite cliffs, and a conglomerate would not have been possible in the building. It is postulated that during the time of the deposition of the Dresbach sands, the Baraboo area was a vast sand flat at times covered over part of its area by water which in an interior non-arid region may have been fresh rather than salty. The quartzite ridges rose as islands above the sands. Such conditions would not have favored colonization by marine organisms. Over some parts of the Baraboo area the sand flats are postulated to have been

dry, and over these the wind built dunes. Dune building would have been favored in protected places about the foot of the quartzite cliffs. During the deposition of the Eau Claire member of the Dresbach formation the upper Mississippi Valley area of deposition permitted marine waters to enter and to maintain conditions suitable for marine organisms, and as this sea became filled with sediments it may be postulated that its waters were freshened and the marine organisms eliminated.

FRANCONIA FORMATION.

General Considerations.

In the western part of Wisconsin and in Iowa and Minnesota the strata lying immediately above the Dresbach formation were designated the Franconia formation from the village of that name in Minnesota. In central Wisconsin a formation with characteristics much like the Franconia and holding the same general stratigraphic position was designated by Ulrich the Mazomanie from the village of that name on the Wisconsin River. Formerly it was rather generally believed that only a single formation was concerned and that the Mazomanie was equivalent to the Franconia. Ulrich then advanced the view that there are two distinct formations, the Mazomanie representing an invasion from the east and the Franconia from the west, and the former overlapping the latter. Little evidence was advanced to support this view. Recent studies have shown the Mazomanie faunas to extend westward beyond the Mississippi and the Franconia faunas to underlie those of the Mazomanie wherever the lower part of the succession is fossiliferous. Moreover, Pentland's[5] study of the Franconia and Mazomanie shows a homogeneity of mineral content which could hardly have been possible had the materials been derived from different regions. As the term Franconia has priority it is here used, and it is recommended that the term Mazomanie be abandoned or given rank as a member.

The Franconia is disconformable on the Dresbach, the disconformity in places having a relief of 2 to 3 feet, but in other places nothing is present to indicate disconformity. A con-

[5] Pentland, A., The Heavy Minerals of the Franconia and Mazomanie Sandstones, Jour. Sed. Pet., 1, pp. 23-26, 1931.

glomerate is frequently present at or several feet above the contact, and not uncommonly there are several thin conglomerates at different levels above the base. A feature distinguishing the Franconia from the underlying Dresbach is the presence of glauconite in the former. The appearance of fossils, worm burrows, glauconite, and dolomite strata readily serve to distinguish the Franconia from the Dresbach.

The basal beds of the Franconia constitute the Ironton member (Ulrich) and represent reworked Dresbach, nearly everything other than fossils and the glauconite coming from the underlying strata, and they carry a fauna which is considered an adaptation to shore conditions. The member has not been definitely recognized within the Baraboo Range but is present on its south flank. It is known from many places outside the Baraboo area. The maximum thickness of the Ironton is about 45 feet. A fauna which belongs to the Ironton is that collected in Fox Glen on the northeast flank of the Range from several feet of red and green shales. The species in the following list, trilobites excepted, are all limited to the locality. The trilobites have undoubted Ironton affinities.

Dendrograptus ? sp. undet.
Parobolus pheres (Walcott).
Linguella sp. nov.
Lingulepis (Westonia?) sp. nov.
Acrotreta nox Walcott.
Camaraspis convexus (Whitfield).
Housia sp.
Elvinia sp.
"Aglaspis" sp. undet.

Over the western half of the Baraboo Basin the basal beds of the Franconia consist of thin-bedded, gray and buff, more or less purple-mottled dolomitic sandstones or sandy dolomites with thickness ranging to around 15 feet. These strata are younger than the Ironton and contain faunas designated the Eoorthis and *Billingsella major*.

The EOORTHIS FAUNA is found in a sandy dolomite or dolomitic sandstone from which fossils were collected at Skillet Falls and northwest of North Freedom. At the latter locality the rock consists of pebbles of sandy dolomite in a matrix of the same material containing many *Billingsella major*. The pebbles contain a variety of *E. remnicha*.

Over the upper Mississippi Valley, *E. remnicha* characterizes a horizon which nowhere exceeds 5 feet in thickness. It has been found as far north and west as Durand, Wisconsin, and Red Wing, Minnesota. Within the Baraboo Basin it is the lowest fossiliferous zone of the Franconia, but in other parts of the upper Mississippi Valley region three earlier fossil zones are known which in descending order are known as the *Irvingella major* zone, Camaraspis zone, and lower Ironton zone. The upper two of these zones are present to the north and west only a short distance from the quartzite hills, and the characteristic trilobite of the *Irvingella major* zone was described from a railroad cut about a mile northwest of Ableman Narrows.

The BILLINGSELLA MAJOR FAUNA is confined in the Baraboo Basin to the lower dolomitic beds of the Franconia. A single brachiopod, *Billingsella major* Walcott, occurs abundantly at the same localities where slightly lower layers have yielded Eoorthis. Walcott secured his type specimens of the characteristic species at the Well's farm, 2 miles west of Baraboo.

Billingsella major is not known outside the Baraboo Basin, but it shows a general resemblance to Ptychaspis zone forms. If the zone which it characterizes is indeed related to the Ptychaspis zone, the important intra-Franconia hiatus known to occur in the Baraboo Basin lies between the Eoorthis and the *Billingsella major* zones.

Succeeding Franconia strata in the Baraboo Basin are about 50 feet thick and consist entirely of white to yellow, mostly fine to medium-grained sandstones. There is much short foreset cross-lamination with the foresets inclined in many directions. The strata range in thickness up to about 2 feet and are penetrated more or less abundantly by variously orientated worm borings. The upper 10 to 12 feet differ in being highly glauconitic and in having a deep green color. At least four major faunal zones are found in the 50 feet of Franconia sandstones inside the basin, which in ascending order are the Ptychaspis, Prosaukia, Briscoia, and Upper Greensand faunas.

The PTYCHASPIS FAUNA occurs in a zone of pink to yellow, medium-grained sandstone full of worm borings. The zone is absent in some places in the Baraboo Basin, and higher strata lie upon the basal dolomitic beds. Outside the Range

and particularly on the west flanks many feet of Franconia strata intervene between the Ptychaspis beds and the dolomitic beds below.

Fossils of the Ptychaspis zone include the following:

Dicellomus sp. nov.
Billingsella sp.
Finkelnburgia sp. nov.
Ptychaspis granulosa var.
"Conaspis" anatina (Hall).
"Ellipsocephalus" curtus Whitfield.
Saratogia wisconsinensis (Owen).

The last three trilobites in this list have wide distribution over the upper Mississippi Valley where they are associated with *Ptychaspis granulosa* (Owen), *P. striata* Whitfield, *Pseudoagnostus josepha* (Hall), and *Billingsella pepina* (Hall). The Ptychaspis zone occurs over the entire upper Mississippi Valley, generally holds a position near the middle of the Franconia formation, and succeeds a zone characterized by *Conaspis* and *Wilbernia.*

The PROSAUKIA FAUNA occurs in the lower part of the white to yellow, medium-grained sandstone which makes up the bulk of the Franconia inside the syncline. It is Ulrich's original Mazomanie fauna, and the following list includes most of the diagnostic species:

Syntrophina primordialis (Whitfield).
Prosaukia sp. nov. 1.
Prosaukia sp. nov. 2.
Chariocephalus whitfieldi (Hall).
Irvingella sp. nov.
Saratogia sp. nov.

The undescribed species in the above list are recognized as very reliable index fossils for the Prosaukia zone as developed in central Wisconsin. *C. whitfieldi,* however, was described from greensands occurring near the middle of the Franconia along the Mississippi River, where it is associated with *Syntrophina primordialis* (Whitfield), *Prosaukia misa* (Hall), *Ptychaspis minicaensis* (Hall), and *Saratogia hamulus* (Hall).

The BRISCOIA FAUNA is found in the upper two-thirds of the white to yellow sandstone which comprises the bulk of

the Franconia formation inside the Baraboo syncline. The fossils include:

Arenicolites woodi Whitfield.
Finkelnburgia ? (2 species).
Syntrophina barabuensis (A. Winchell).
Syntrophina sp. nov.
Prosaukia sp. nov. (3 varieties).
Briscoia sp. nov. 1.
Briscoia sp. nov. 2.
Prozacompsus sp. nov.
Platycolpus sp. nov.

The Briscoia beds are known definitely to succeed immediately those bearing a Prosaukia fauna, and it can be demonstrated that they are, in turn, succeeded by the glauconitic sandstone which forms the closing member of the Franconia not only locally but over most, if not all, of the upper Mississippi Valley. This latter relationship may be observed three and one-half miles south-southwest of North Freedom, Sauk County, and south of Woods Quarry, near Baraboo, Sauk County.

The UPPER GREENSAND faunal zone is not given a faunistic designation as most of the species are undescribed. As connotated by the designation of the zone the strata consist of the greensands which form the topmost part of the Franconia formation in the Baraboo Basin and over most of the upper Mississippi Valley. Fossils are few and include the following:

Obolus sp. nov.
Calvinella sp. nov.
Saukiella minor Ulrich and Resser.
Saukiella sp. nov. (large).
Briscoia sp. nov. 3.
Bynumia ?? sp.
Illaenurus sp. nov.
Platycolpus ?? sp.
"Conaspis" sp. nov. ("C" anatina type).
Dikellocephalus postrectus Ulrich and Resser.
Undet. genus ancestral to Eurekia.

With but one or two exceptions, all the species in the above list are known from other parts of Wisconsin.

Outside the quartzite ridges the Franconia is somewhat different from what it is within the basin. The Ironton member is commonly, but not always, present. The overlying dolomitic member has a maximum thickness of about 4 feet

and is not always present. North and west of the area this member is succeeded by about 8 feet of platy micaceous siltstones, known as the "micaceous shale," with colors ranging from buff to gray. The mica abundant on the bedding planes is detrital muscovite. The chief mineral in this member is finely divided quartz, and clay minerals are generally wanting. Glauconite is invariably present, and fossils are common.

Near the quartzite ridges the Ironton, dolomitic, and "micaceous shale" members are represented by conglomerates or by sandstones containing much gravel, and at immediate contact with the quartzite ridges there are numerous large, more or less rounded fragments of quartzite. Outward from the ridges the quartzite fragments progressively decrease in dimension and finally pass into the pebble and granule grades. This conglomerate has a maximum thickness of about 40 feet, and a splendid exposure is in the north end of Ableman Gorge where these coarse clastics, there corresponding to the lower members of the Franconia, extend outward for more than one-eighth mile from the quartzite. From shaly layers among the coarse gravels fossils representing the Eoorthis and Conaspis horizons have been collected.

The great extent of Franconia gravels is found on the outside, but not on the inside, of the ring of islands, and distribution attests the great power of the waves and currents in the open waters, and depths of water commensurate with the power of the waves during the times of deposition. In the protected interior of the ring of quartzite islands the marginal conglomerates represent little more than the little reworked talus about the quartzite ridges.

The contrast between the absence of gravels in the Dresbach and the abundance in the Franconia is extremely striking, particularly where the rocks of both can be seen in the same section as is the case on the north end of Ableman Gorge. Extremely different environmental conditions of deposition must have existed within and without the quartzite ring of islands.

Succeeding strata of the Franconia outside the range, except the topmost beds, consist of lenticularly interbedded glauconitic sandstones and sandy dolomites. The sandstones are soft, are dominantly fine-grained, and have colors ranging from white or gray to light brown. The dolomitic beds have gray to light brown colors.

The uppermost 10 to 15 feet consist of fine to medium-grained greensand. Most exposures carry thin streaks of

buff-colored, sandy dolomite, and thin laminations of silty shale occur locally. Small, variously orientated worm burrows are rather common.

Away from the immediate vicinity of the ranges, the Franconia formation above the Ironton, is uniformly 120 to 130 feet thick.

It is rather difficult to discuss the Franconia faunas outside the basin due to the fact that immediately adjacent to the quartzite the sediments are so coarse as to preserve few organic remains, whereas if the scope of the consideration be extended to sections away from the effects of the quartzite, there is no natural limit to circumscribe the area to be considered. At the present time it is hence thought best to do no more than give the faunal succession in central Wisconsin outside the Baraboo Basin. This is as follows:

Upper Greensand Fauna.
Briscoia Fauna.
Prosaukia Fauna.
Ptychaspis-Saukaspis Fauna.
Conaspis-Wilbernia Fauna.
Eoorthis Fauna.
Irvingella major Fauna.
Camaraspis Fauna.

The most complete representation of this faunal succession occurs north and northwest of the Baraboo Basin in the vicinity of Reedsburg and the Dells. South of the ranges, the Eoorthis and Conaspis zones have been recognized near Denzer, and farther south along the Wisconsin River in southern Sauk County the Conaspis, Ptychaspis, and Prosaukia horizons have been found. Fossiliferous Ironton is definitely absent in southern Sauk County. Fossils of the Eoorthis and of the Conaspis zones were collected from two different layers of green shale between coarse quartzite gravels in the gravel pit in the north end of the Upper Narrows.

The Franconia within the quartzite ridges differs from that without as follows:

1. Within the quartzite ridges the Franconia is less than half as thick as outside.
2. Dolomitic cement is less common within the Range, but most of the exposures are near the quartzite ridges where dolomite would be least likely to occur.
3. Conglomerates are much more strongly developed on the outer margins of the quartzite ridges.
4. Cross-lamination is more prevalent outside the Range.

Minerals of the Franconia Formation.

The minerals of the Franconia formation are dominantly quartz and dolomite, the former allothogenic, the latter authigenic. Glauconite, also thought to be authigenic, is extremely abundant in some beds, particularly in the upper greensand. As shown by Pentland,[6] the dominant heavy mineral is garnet, but about the Baraboo area there is considerable variation in the quantity of this mineral. The sandy dolomite has the same mineralogy as the Dresbach, but one sample showed dominant garnet. The micaceous shale member has abundant muscovite in addition to quartz and common glauconite and of the heavy minerals contains dominant zircon and garnet. Dominant garnet prevails in the middle sandstone and the upper greensand. The quantity of zircon in these two members is small. The garnet ranges from colorless through light pink to dark pink. Tourmaline is present as a few particles in all samples and is commonly brown, and more rarely, blue. Quantities of rutile and of martite were observed in several samples. There are rare grains of anatase, tremolite, topaz, and hornblende. Leucoxene or ilmenite, microcline, and orthoclase were found in small quantity in all samples.

Environment of Deposition of the Franconia Sediments.

The presence of mud cracks on several levels in the Franconia formation at places outside the Baraboo area proves the waters to have been shallow there at those times. The cross-lamination is in thin beds with many directions of inclination, suggesting that new additions of sands were not abundantly made and that previously deposited sands were repeatedly stirred and redeposited. The presence of glauconite in greater or less abundance throughout the formation is in harmony with the concept of a slow rate of deposition, as the origin of this mineral is thought to require such conditions. It seems probable that the glauconite originated in the environment of deposition, although it is likely that it underwent considerable transportation back and forth before finally coming to rest. The character and abundance of the fossils proves a marine environment.

[6] Pentland, A., op. cit.

TREMPEALEAU FORMATION.

General Considerations.

The term Trempealeau as now used by Ulrich applies to strata formerly designated the St. Lawrence formation. This term as originally used by Winchell included only the basal dolomite (Mendota of Irving), and succeeding "shale" (Lodi of Ulrich). The sandstone between the Lodi member and Oneota dolomite was designated Jordan by Winchell and Madison by Irving. Recent work indicates that the basal part of this sandstone grades imperceptibly downward into the Lodi member of Winchell's St. Lawrence. The writers therefore follow Ulrich in recognizing an upper sandstone, the Madison, and in regarding the lower sandstones as members of a formation which includes the underlying "shale" and dolomite. This constitutes the Trempealeau formation with members arranged in descending order as follows: Jordan sandstone, Lodi shale, and St. Lawrence (Mendota or Black Earth) dolomite.

It seems probable that the Trempealeau holds disconformable relationships to the Franconia, since a conglomerate composed of cobbles, pebbles, and granules of greensand, silt, and sandy dolomite resting on an erosion surface of the Franconia may be identified in most outcrops where the base of the Trempealeau is exposed.

Within the Baraboo Basin, the Trempealeau formation may be satisfactorily divided into three members:

1. A basal greensand and greensand conglomerate member.
2. A dolomitic member, comprising the rather thick-bedded dolomite below (Mendota) and the platy, calcareo-siliceous siltstone above (Lodi).
3. A sandstone member which terminates the succession (Jordan).

The boundaries between these divisions are rarely sharp, and there is, moreover, considerable lateral variation. As the quartzite ridges are approached all members pass into sandstones and finally into conglomerates. The conglomerates in Parfrey's Glen are at the base of the Trempealeau.

The Trempealeau formation within the quartzite ridges is in general similar to that without, which is taken to indicate that all except the high parts of the quartzite ridges were submerged and that large parts had been buried beneath Dresbach and Franconia sediments, with the consequence that the ridges had lost much of their previous environmental influence.

The conglomerate and basal greensand member is wanting in some places and in others has a thickness up to about 15 feet. It is usually less than 5 feet thick, and it contains few fossils.

The dolomites comprising the lower part of the second member are fairly well stratified with beds ranging from about 1 to 8 inches thick. The color is buff to tan with purple mottling in some beds. Considerable glauconite is locally present. Toward the top the dolomite becomes thin-bedded and impure from contained silt, and at numerous places beds of greenish-gray to bluish-green calcareous siltstone are interbedded. These pass upward into gray, yellow, and purple siltstones which in the upper part contain thin units of light brown, gray and buff, fine-grained sandstones which are transitional to the overlying sandstones. In some places, particularly south of the south quartzite ridge, these transitional beds are not present, and the coarse-grained sandstones of the Jordan member rest directly upon the dolomitic siltstones. Within and west of the basin the fine-grained sandstones are well developed. The dolomitic member has a maximum thickness approximating 30 feet.

The upper sandstone member Jordan sandstone, consists of medium to coarse-grained sandstones with yellow, tan, and occasionally red colors. The sandstone is usually very friable, and bedding is irregular and very poorly defined. Worm burrows are usually present. Adjacent to those parts of the quartzite ridges which were not yet buried beneath the sediments, the Jordan sandstone passes into coarser materials. The thickness is estimated at 30 to 50 feet.

The Mendota Dolomite Problem.

The Mendota dolomite in the Baraboo Basin is fossiliferous at the two localities of Wood's Quarry, 3 miles southwest of Baraboo, and Eikie's Quarry, a short distance northwest of Pine Bluff. For faunal reasons, Ulrich considers these exposures to be much younger than Trempealeau in age, and in fact places them in the lower part of his Ozarkian System. The writers do not concur in this conclusion, and therefore consider it advisable to describe the localities and the fauna in greater detail than might otherwise be necessary.

The dolomites under consideration have a maximum thickness of about 20 feet and lie immediately above the basal

greensand member of the Trempealeau. The stratification is good except at places where algal deposits are common. The color is gray to buff, more or less mottled with purple. Glauconite is present in isolated particles or in thin streaks of sandy clay or silt and may impart a green shade.

The Baraboo exposures are among the classic areas which have yielded the Mendota fauna and are the sources of Whitfield's original fossil material. The other areas are near Madison and in the Black Earth Valley, west of Madison. The Black Earth faunal assemblage is stated by Ulrich to possess mutational differences which distinguish its species from those of the Baraboo and Madison localities, and he places the strata of the Black Earth localities well down in the Upper Cambrian and the Madison and Baraboo occurrences in his Ozarkian. However, there is no known stratigraphic evidence supporting an age separation of the two assemblages, but, on the contrary, all the evidence indicates that the Black Earth, Mendota, and St. Lawrence are different expressions of the same dolomite. Moreover, all the known fossils are casts and hence subject to the limitations the preservation imposes. The writers prefer to wait for better evidence than has yet been presented before they can give serious consideration to Ulrich's interpretation of the Mendota dolomite.

THE LODI FAUNA.

The calcareo-siliceous siltstone (Lodi "shale") which overlies the St. Lawrence, Mendota, and Black Earth dolomites and which with this dolomite comprises the middle member of the Trempealeau has a characteristic fauna which includes the following:

Westonia aurora (Hall).
Saukia whitfieldi Ulrich and Resser.?
Tellerina sp. nov. 1.
Dikelocephalus hotchkissi Ulrich and Resser.
Dikelocephalus granosus U. & R.
Prozacompsus sp. nov. 2.
Illaenurus quadratus Hall, var. nov.

Most of the paleontologic material collected in the Baraboo Basin came from a single locality north of North Freedom, which was called to the writers' attention by Trowbridge.

The Devils Lake Sandstone Problem.

Consideration of Trempealeau members and faunas involves examination of the problem of the Devils Lake sandstone. The type exposure of the Devils Lake sandstone is on the "Alps" farm near the northeast end of the Devils Lake Gorge where less than 10 feet of sandstone are exposed high up in the inner flank of the South Range. The sandstone contains rounded pebbles of quartzite and numerous worm borings. The color is a pinkish cream. A second locality containing the Devils Lake sandstone fauna was found within the limits of the Trempealeau formation on the outer flank of the North Range at a point about 6 miles east of Reedsburg. The topographic position of the outcrop at the "Alps" places it in the Trempealeau formation, of which the Devils Lake sandstone is considered a shore phase. The affinities of the fauna may be judged from the following list of species:

Cf. Ophileta (Raphistoma) primordialis A. Winchell.
Prosaukia sp. nov. 4.
Tellerina sp. nov.
Briscoia sp. nov. 4.
Briscoia sp. nov. 5.
Platycolpus sp. nov.
Plethopeltis sp. nov.
Plethometopus sp. nov.
Triarthropsis sp. nov.
Undet. trilobite, resembling Triarthropsis.

Ulrich[7] in his discussion of the alleged break between the Cambrian and Ozarkian in Wisconsin assigned 100 feet of strata to the Devils Lake formation and made it the basal formation of his Ozarkian system. By including numerous exposures which the writers have since found belong to other horizons than that to which the type exposure of the Devils Lake sandstone belongs, Ulrich achieved a much wider stratigraphic and geographic extent for his formation than the facts warrant. It can now be demonstrated that (1) the thick conglomerate at the north end of Ableman Gorge, correlated by Ulrich with the Devils Lake sandstone, is lower Franconia as it holds the interval belonging to that horizon and has the micaceous shale fossils, and (2) that the conglomerate at

[7] Ulrich, E. O., Notes on new names in table of formations and on physical evidences of breaks between Paleozoic systems in Wisconsin. Tran. Wisconsin Acad. Sci., 21, pp. 104-105, 1924.

Parfrey's Glen, also correlated by Ulrich with the Devils Lake sandstone, has the stratigraphic position of the basal Trempealeau. His arrangement, therefore, involves the correlation of a conglomerate at the base of the Franconia, a conglomerate at the base of the Trempealeau, and the Devils Lake sandstone which holds a position in the Trempealeau. It is recommended that the term be abandoned as it is certainly no more than a shore phase of a part of the middle of the Trempealeau.

Minerals of the Trempealeau Formation.

The mineral suites of the Trempealeau formation are the same as the Franconia except that the Norwalk sandstone has a varied mineralogy, and tourmaline is locally prominent. Glauconite is conspicuous in the greensand at the base and is present in many samples from the Lodi member. Microcline and orthoclase are found in many samples in small quantities, and some samples contain as much as 2 to 3 per cent. Garnet is the dominant heavy mineral.

Environment of Deposition of the Trempealeau Sediments.

The two lower members of the Trempealeau formation were deposited under marine conditions in waters which were probably shallow at all times. Deposition seems to have been slow except for the basal conglomerate and the overlying greensand, which are thought to be largely detrital from the Franconia. It seems probable that the upper part of the Norwalk member records emergence. At the close of the Trempealeau period only the highest parts of the Baraboo quartzite ridges remained unburied.

MADISON FORMATION.

General Considerations.

The Madison formation is composed of sandstones which along the Mississippi overlie the coarse upper beds of the Trempealeau. In central Wisconsin the relations are slightly obscure, because this underlying coarse sandstone is not so conspicuously developed. In this latter region, however, occasional fossils support the lithologic evidence.

No Madison is known in the east end of the Baraboo Basin, although the formations that bound it above and below are

both known there: It may be present but not exposed. South of the South Range the Madison consists of fine to medium-grained, light brown to white, rather thin-bedded, dolomitic sandstone which is more or less ripple marked and cross-laminated. North of the South Range on the west end of the basin the dolomite content is small, and the Madison consists of white to light brown, ripple marked, cross-laminated, medium-grained sandstone. Sorting is rather poor, especially in the lower part of the formation. Locally the upper beds are so firmly cemented as to simulate quartzite. The thickness in this area ranges from 10 to 20 feet.

The fauna of the Madison includes such genera as *Tellerina, Plethometopus, Plethopeltis, Entomaspis, Hyolithes,* and *Lingulepis.* No fossils have been found in the Madison in the Baraboo region.

Minerals of the Madison Formation.

The dominant mineral in the Madison sandstone is quartz, and ordinarily dolomite holds second place. Microcline, orthoclase, and plagioclase are present in some samples in small quantity. Garnet is the dominant heavy mineral. Leucoxene, ilmenite, zircon, and tourmaline are present in some samples but absent in most.

Environment of Deposition of the Madison Sediments.

It is thought that the materials of the Madison sandstone were deposited in very shallow water under environmental conditions rather unfavorable for marine life. Vast sand flats covered by fresh, or salt waters, or alternations of each, are postulated.

The Ordovician Period and System.

The Ordovician system is represented in the Baraboo area by the Oneota, St. Peter, and Platteville formations. In addition high level river gravels on the east bluff of Devils Lake contain Maquoketa and Silurian fossils.

The physical evidence for the Cambrian-Ordovician break in the upper Mississippi region is not conspicuous. The lowest

formation, the Oneota, is considered to rest unconformably on the Madison sandstone, as there seems to be an erosion surface between the two formations, above which a conglomerate is not uncommon. This conglomerate at some localities contains pebbles and cobbles of quartzite which are many miles from any possible source. A rather decided faunal break supports the stratigraphic evidence.

ONEOTA FORMATION.

General Considerations.

The Oneota formation has little development in the Baraboo area. The basal beds are more or less sandy, and some beds are entirely composed of sandstone. The succeeding dolomites are hard and finely crystalline. Many beds in the lower 30 feet of the formation are oolitic, and chert nodules and lenses are present more or less throughout. The chert is gray and yellow, and in the oolitic beds it likewise is oolitic. Mud cracks are not uncommon, and some of the sandstone layers are ripple marked. Many beds are composed of dome-shaped bodies due to algae. In addition to the algal structures, other fossils occur in the Oneota, but only those in the chert nodules are well preserved. None is known from the Baraboo region.

On account of the pre-St. Peter and the post-Devonian erosion the Oneota is less than 80 feet in thickness in the Baraboo area, and it is generally absent. It exists in small thickness over the east end of the basin to the east and north of Pine Bluff; larger and better exposures are present over the west end. Near such of the quartzite ridges as had not been buried in Cambrian sediments, granules and small angular pebbles of quartzite are present in the basal beds. No contact of the Oneota with the quartzite has been seen, but some of the conglomerates about the quartzite ridges are certainly marginal phases of the Oneota formation.

Minerals of the Oneota Formation.

The mineral suites of the sandstones in the basal part of the Oneota formation are essentially those of the Franconia and Trempealeau formations. Some of the quartz grains have apatite and rutile inclusions, and orthoclase and plagio-

clase are common in some samples. The dolomite strata contain quartz grains, and glauconite is common in some beds.

Origin of the Oneota Sediments.

The Oneota dolomite is of marine origin. The waters of deposition were shallow and within the zone of light, otherwise the algae could not have precipitated the carbonates. The rate of deposition is not known, but it may have been more rapid than some of the thin-bedded greensands of the Franconia formation.

SHAKOPEE FORMATION.

The deep pre-St. Peter and the post-Devonian erosion eliminated all of the Shakopee formation if it ever was present.

ST. PETER FORMATION.

General Considerations.

Following deposition of the dolomite formations known as the Oneota and the Shakopee, the upper Mississippi Valley emerged from the sea, was subjected to erosion, and developed a surface to the mature stage of the erosion cycle. This surface had a maximum relief of three hundred feet or more. The St. Peter formation was deposited upon this surface in marked disconformity on the Oneota or some lower formation. The formation is well exposed in the outliers of Pine Bluff and Gibralter Bluff.

The base of the St. Peter consists of green clays and red or other colored sands in which quite commonly there is much residual chert derived from the Oneota or the Shakopee. The St. Peter above the basal strata is almost entirely composed of sandstone of which the grain size ranges from very coarse to fine flour-like silts. Cementation and sorting ordinarily are poor, bedding is very poorly defined, cross-lamination of varied inclination is common, and colors range from white through yellow to reddish-brown. Some of the conglomerates about the highest parts of the quartzite ridges are undoubtedly of St. Peter age. No fossils are known from the St. Peter of the Baraboo area. The maximum exposed thickness, 111 feet, is at Gibralter Bluff.

Minerals of the St. Peter Formation.

Quartz is the chief mineral in the St. Peter sandstone, and many of the particles show enlargement. At Pine Bluff the heavy minerals are like those of the Dresbach except that tourmaline is more common in the St. Peter. At Gilbralter Bluff the mineral suite of the St. Peter sandstone is intermediate between typical Franconia and typical Dresbach. Zircon, pink garnet, and ilmenite are present in nearly every sample.

PLATTEVILLE FORMATION.

The Platteville formation is known in the Baraboo area only at Gibralter Bluff where less than 10 feet of hard, finely crystalline, thin-bedded, more or less sandy, gray dolomite remain. The sand in the dolomite has a typical Franconia suite of minerals with dominant garnet. Fossils are present, but they have not been studied.

Other Platteville strata are certainly represented in some of the conglomerates found about the highest of the quartzite ridges.

PROVENANCE OF THE PALEOZOIC SEDIMENTS.

The marked differences in the heavy minerals of the Paleozoic and the Pre-Cambrian in the Baraboo area indicate that sources other than the Baraboo Pre-Cambrian were the chief contributors to the materials of the Paleozoic sediments. The Baraboo quartzite may have obtained considerable contribution from the underlying crystallines, but the mineral composition of this quartzite strongly suggests that sedimentary terranes were the provenance for most of the materials. Of the local Pre-Cambrian rocks the Baraboo quartzite was probably the chief contributor to the Paleozoic sediments, but it did not contribute the garnets, tourmalines, feldspars, and most of the zircons in these strata. It seems obvious that other provenances are responsible for the major part of the Paleozoic sediments.

Where and what are these provenances? This remains to be determined. The predominance, among the heavy minerals, of those types most resistant chemically and physically, with the decided rarity of the feldspars and ferro-magnesian minerals suggests that the direct provenances of these sedi-

ments were sedimentary terranes. That some contributions were made by the quartzites is obvious in the granules, pebbles, and larger fragmental materials that are so conspicuous in most of the formations at and near the contacts with the quartzite ridges. The character of the heavy minerals in the Paleozoic strata within the ridges indicates that large contributions were brought in from without. This could have been accomplished by the currents flowing through the many gaps in the quartzite ridges, and there might also have been small contributions via the atmosphere.

WASHINGTON, D. C.

THE CARBONIFEROUS AMMONOID GENUS DRYOCHOCERAS, A SYNONYM OF SAGITTOCERAS.

A. K. MILLER.

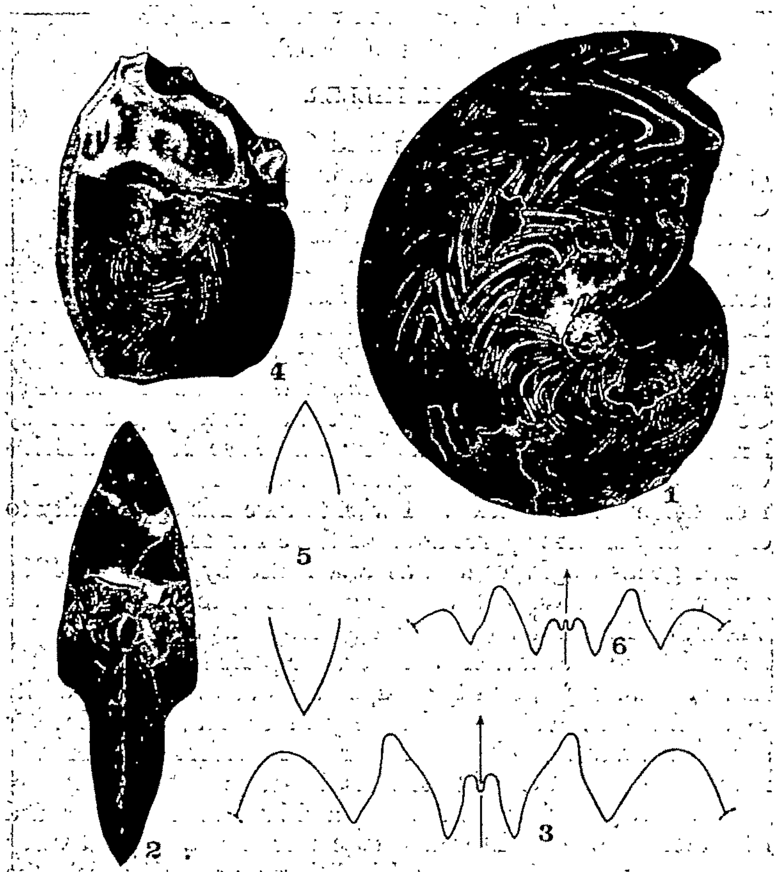
In an obscure publication entitled *Geology of the Stonewall quadrangle, Oklahoma*, and issued in 1924 as Bulletin 2 of an Oklahoma "Bureau of Geology," G. D. Morgan proposed the generic term *Dryochoceras* for a specimen from the basal part of the Caney shale (Mississippian) of Oklahoma that he described (pp. 185-186) as *D. brainerdi.*[1] Morgan's illustrations and description indicated to me that his species probably represented the rare genus *Sagittoceras*[2] and I accordingly requested a loan of his type specimen which was deposited at Columbia University; my request was readily granted by Dr. G. Marshall Kay of that institution. Also, Mr. John Britts Owen of Clinton, Missouri, kindly loaned for study specimens from his private collection. I wish to take this opportunity to express my sincere appreciation of these favors.

The genus *Sagittoceras* was established by Hind[3] in 1918 and was based on a single incomplete specimen from the Viséan of England which Hind described as *S. acutum.* Its most distinctive characters are the acute periphery of its conch, its small umbilicus, and the shape of its sutures; each of its external sutures consists of a very broad large prominently subdivided ventral lobe, narrower (but nevertheless broad) narrowly rounded external saddles, broad angular first lateral lobes with sigmoidal ventral sides, and broad shallow rounded first lateral saddles. Morgan's type specimen of *Dryochoceras* shows all of these features and it differs appreciably from the genotype of *Sagittoceras* only in that the small median tertiary lobe on its venter is not subdivided. This difference is so minor that it certainly should not be considered of generic value, and whereas these two forms are not conspecific they are clearly congeneric. The generic term *Sagittoceras* has priority and *Dryochoceras* is therefore to be suppressed as a synonym of it.

[1] In the legend of the plate the specific name is misprinted "GRAINERDI."

[2] Not *Sagitticeras* Buckman (*Type ammonites*, pt. 23, 1920, p. 19) of the Jurassic of England with which the similarity of spelling might lead to confusion.

[3] Hind, Wheelton, On the distribution of the British Carboniferous goniatites, with a description of one new genus and some new species: Geological Magazine, decade 6, vol. 5, pp. 446-447, 1918.



Figs. 1-3. *Sagittoceras brainerdi* (Morgan). Lateral and ventral views and diagrammatic representation of a suture of holotype, x 1; from basal part of Caney shale of Oklahoma (near northeast corner of sec. 21, T. 3 N., R. 6 E.). This specimen is in the paleontological collections of Columbia University, where it bears the catalogue number 18,475.

Figs. 4-6. *Sagittoceras acutum* Hind, the genotype of *Sagittoceras*. Lateral view and diagrammatic representations of the ventral outline and of a suture of the holotype, x ⅔; from the Viséan (upper *Dibunophyllum* zone) of Keal Hill, Craven, Yorkshire, England. After Hind.

Hind compared *S. acutum* with *Brancoceras enniskillenense* Foord, an acutely keeled goniatite of the Lower Carboniferous of Ireland and England, but he recognized that the relationship

is not close. Foord[4] states that an impression of the sutures of the type specimen of *B. enniskillenense* "left no doubt as to their being those of *Brancoceras*" Hyatt [=*Imitoceras* Schindewolf] and therefore the similarity of these two species is entirely superficial.

In 1924 Bisat[5] referred to *Sagittoceras Goniatites complicatus* de Koninck and *G. vesiculifer* de Koninck of the Viséan of Belgium and England, but he recognized that they "may not be allied to *acutum*." The conchs of both of these forms are rounded rather than angular ventrally and their sutures though somewhat similar to those of the genotype of *Sagittoceras* present certain significant differences particularly in the relative lengths of the ventral and lateral lobes and in the shape of the lateral lobes. These two species seem to be more similar to the genotype of *Milleroceras* than to that of *Sagittoceras* but it is very doubtful if they are closely related to either.

Two other species have been referred to *Sagittoceras* by Bisat;[6] these are *Adelphoceras meslerianum* Girty of the Caney shale of Oklahoma and possibly the Viséan of England and Germany and *Goniatites? coronula* Roemer of the Viséan of Germany and possibly England. The sutures of the type specimens of *A. meslerianum* are not markedly different from those of the genotype of *Sagittoceras* and the whorls though low and broad during adolescence are compressed laterally at maturity so that the conch is subdiscoidal in shape; the venter however is rounded rather than acute and this is probably sufficient to differentiate this form generically from typical *Sagittoceras*—it should be referred to the genus *Girtyoceras* as the generic term *Adelphoceras* was used first in connection with nautiloids. The type specimens of *Goniatites? coronula* are small, very broadly umbilicated forms in which the volutions are depressed and are subquadrate in cross section, the venter is very broad and is broadly rounded, and the ventro-lateral margins are crenate; the sutures are not preserved on any of the types and therefore their generic affinities are uncertain

[4] Foord, A. H., Monograph of the Carboniferous Cephalopoda of Ireland, Part V: Palaeontographical Society, vol. 57, p. 209, 1903.

[5] Bisat, W. S., The Carboniferous goniatites of the North of England and their zones: Yorkshire Geol. Soc. Proc., vol. 20, pt. 1, p. 83, 1924.

[6] Bisat, W. S., The Carboniferous goniatite zones of England and their Continental equivalents: Congrès pour l'avancement des études de stratigraphie Carbonifère, C. R., p. 125, 1928; and On *Cravenoceras leion*, sp. nov., the basement goniatite of the Namurian, Upper Carboniferous: Leeds Geol. Assoc. Trans., part 20, 1923-1929, pp. 31, 32, 1930.

but they are so totally unlike the genotype of *Sagittoceras* that there seems to be little reason to regard them as congeneric with that species.

Patteisky[7] and Knopp[8] have referred to *Sagittoceras* numerous specimens from the Lower Carboniferous of the Sudetic Mountains on the border between Czechoslovakia and Germany. A canvass of most of the leading geological libraries of this country has failed to locate a copy of Patteisky's work, but apparently all of the forms dealt with by him are included in Knopp's study. In so far as I am able to tell from Knopp's illustrations and descriptions none of the goniatites in question has an angular venter or is similar enough to the genotype of *Sagittoceras* to be considered congeneric with it. However, Knopp states that Patteisky found specimens that apparently were conspecific with *Sagittoceras discus* (Roemer) as figured and illustrated by Schmidt,[9] and Schmidt's specimens apparently are true representatives of *Sagittoceras* s. s.

For the sake of completeness it should be mentioned that Delépine[10] has recently stated that an undescribed species of *Sagittoceras* occurs in southwestern France in strata that are believed to lie near the Viséan-Namurian contact. Until illustrations and descriptions of this form are published it will of course not be possible to express an opinion in regard to its affinities, but it should be pointed out that the generic identification was made solely on the basis of the shape of the conch and the surface ornamentation as the sutures were not preserved on any of the numerous specimens obtained.

In 1925 Schmidt[11] published diagrammatic cross sections of five species of goniatites with acute venters. The specimens on which these were based all came from the Viséan of Germany and Schmidt referred them (in part incorrectly, I believe) to *Goniatites discus* Roemer, *Homoceras brüningianum* Schmidt, *Adelphoceras meslerianum* Girty, *Eumorphoceras*

[7] Patteisky, K., Die Geologie und Fossilführung der mährisch-schlesischen Dachschiefer und Grauwackenformation, 1930. Herausgegeben vom Naturwissenschaftlichen Verein in Troppau, Č. S. R.

[8] Knopp, L., Ueber die unterkarbonischen Goniatiten der Ostsudeten: Lotos, Bd. 79, pp. 10-13, 1931.

[9] Schmidt, Hermann, Die carbonischen Goniatiten Deutschlands: Preuss. geol. Landesanstalt Jahrb., Bd. 45, p. 577, pl. 21, fig. 16; pl. 24, figs. 10, 11, 1925.

[10] Delépine, G., L'âge des schistes de Mondette (Ariège): C. R. somm. Soc. Géol. France, pp. 157-158, 1931.

[11] Schmidt, Hermann, Die carbonischen Goniatiten Deutschlands: Preuss. geol. Landesanstalt Jahrb., Bd. 45, pl. 21, figs. 16-20, 1925.

burhennei Brüning, and *Goniatites? coronula* Roemer, all of which he placed in the genus *Homoceras*. In Schmidt's figures of these forms considerable variation is evident in the form of the earlier volutions of the conch, in the size and shape of the umbilicus, and in the details of the sutures. In the sutures of the form referred to *G. discus* the ventral lobe is very large and broad and is prominently subdivided, the external saddle is very narrowly rounded, and the ventral side of the first lateral lobe is sigmoidal; these features, which are all characteristic of the genus *Sagittoceras*, serve to differentiate this form from the others figured by Schmidt and whereas *S. discus* (of Schmidt, Roemer?) should therefore be referred to *Sagittoceras* I am uncertain about the generic affinities of the other forms figured.

Schmidt[12] regarded *Sagittoceras* as a synonym of *Homoceras*. The genotype of *Homoceras* is *Goniotites calyx* Phillips of the Viséan of England and possibly Belgium. However, that species was based on a small specimen which Bisat[13] believes is probably an adolescent representative of *Goniatites platylobus* Phillips of the Viséan of England. Be that as it may, the whorls of the type of *G. calyx* are low and broad and are very broadly rounded ventrally, the umbilical shoulders are crenate, and the sutures are considerably different from those of *Sagittoceras acutum*, the genotype of *Sagittoceras*—unless it can be definitely shown that these characters are entirely lost during ontogenetic development, there is little justification for regarding this form as congeneric with *S. acutum*.

Sagittoceras appears to be closely related to the genera *Milleroceras*, *Gurleyoceras*, and *Gonioloboceras*, and it should be associated with them—there is a difference of opinion[14] as to whether these genera should be referred to the Gephyroceratidae or the Glyphioceratidae. The acute venter of *Sagittoceras* serves to differentiate it from *Gurleyoceras*, in which the venter is retuse, and from *Milleroceras* and *Gonioloboceras*, in which the venter is rounded. At least the external sutures of *Milleroceras* and *Gurleyoceras* are comparable to those of *Sagittoceras*, but in *Gonioloboceras* the lobes and saddles are more sharply pointed. The internal sutures of the genotype of

[12] Op. cit., pp. 575-576.
[13] Op. cit., 1924, p. 103.
[14] See Schindewolf, O. H., Neues Jahrb. f. Min., Geol. u. Pal., Ref. 3, Jahrg., p. 1065, 1932; and Miller, A. K., Jour. Pal., vol. 6, 1932, p. 71, and Pal. Zentralblatt, Bd. 2, p. 310, 1932.

Sagittoceras are not known but those of *S. brainerdi* consist of a long slender dorsal lobe and on either side of it a deep narrow rounded saddle, a long slender lateral lobe, and an exceptionally broad shallow broadly rounded saddle which extends clear to the umbilicus. The internal sutures of *S. discus* have been figured by Schmidt[15] and they are comparable to those of *S. brainerdi* but the large lateral saddle next to the umbilicus is broader in the American form.

Very little information in regard to surface ornamentation can be gleaned from the holotype of *S. brainerdi* for, though it is an exceptionally well preserved specimen, it is an internal mold to which only small portions of the very thin test adhere. However, the John Britts Owen Collection contains two representatives of this species from the Caney shale southeast of Ada, Oklahoma, that retain the test. One of these is small but the other, which apparently represents a portion of the living chamber, attained a diameter of at least 5 inches. The growth-lines on both of these specimens are very sinuous; they form broad shallow rounded salients on the dorsal portion of the lateral sides, similar but broader sinuses on the central portion of the lateral sides, and similar but deeper salients on the ventral portion of the lateral sides; they curve strongly apicad as they approach the venter and indicate that that portion of the conch was marked by a deep angular hyponomic sinus. The venter of the large specimen under consideration is marked by a single row of small rounded nodes about 1 mm. apart; traces of these nodes are very distinct on the internal mold of this specimen and they can be discerned also on the holotype.

Summary. From the information presented in the preceding paragraphs it seems clear that *Dryochoceras* Morgan is to be suppressed as a synonym of *Sagittoceras* Hind; that *Sagittoceras* is known to be represented in only the Caney shale of Oklahoma and the Viséan of England and Germany and probably Czechoslovakia, and possibly in the Viséan or the Namurian of France; and that *Sagittoceras* is closely related to *Gurleyoceras, Milleroceras,* and *Gonioloboceras.*

[15] Op. cit., pl. 21, fig. 16.

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PETROFABRICS (GEFÜGEKUNDE DER GESTEINE) AND OROGENESIS.[1]

BRUNO SANDER.[2]

In the space at my disposal I can make but a brief reference to the petrofabric literature of importance to orogenesis since (11).[3] In addition I will touch on some of the very numerous relations between petrofabrics and orogenesis.

I use orogenesis in a wider sense than many tectonists. Likewise, petrofabrics[4] is used in the broad sense of (11), and deformed rocks, crystalline grain fabrics (Korngefüge), etc., are only some of the chapters of petrofabrics. There ought not to be microtectonists and megatectonists working independently of each other, but rather one group of workers investigating the correlations between processes in large and in small units.

The importance of petrofabrics for orogenesis will not be over-emphasized here. As the literature up to now shows clearly, petrofabrics affords sometimes more, sometimes less information than is assumed. There are many problems even of petrotectonic character which can not be solved by petrofabric analysis alone. On the other hand, petrofabric analysis is indispensable for orogenic and many practical problems. The data afforded by new papers are of value even though the diagrams are not correlated with the problems of petrofabrics.

Summarizing the latest petrofabric analyses, one sees many and important new facts, new and independent possibilities for the characterization of geologic bodies, and new problems. The concepts of petrofabrics are growing and changing. Besides the students of the Innsbruck department many other workers from Germany, America, Finland, Italy, and Switzerland have taken part in this work. Investigators from all these countries have worked in the Innsbruck department in spite of the very limited apparatus available, and I for my part owe them many thanks for unpublished analyses.

The mere data of petrofabrics to-day comprise so many

[1] Previous study of petrofabric literature, particularly of E. B. Knopf's paper on Petrotectonics (this Journal, vol. XXV, June 1933), is assumed.

[2] In the translation and editing of this paper I am much indebted to H. W. Fairbairn and E. B. Knopf for their kind assistance.

[3] The numbers in parentheses refer to the bibliography at the end of this paper.

[4] Petrofabrics denotes the study of the internal space relations of a rock. (Editor.)

points of view and raise so many questions that it is possible to consider petrofabrics as an independent study and to pursue it as such. Petrofabric analysis is also important for purely petrographic investigations that seek only descriptive characteristics of rocks. For instance it is a totally different thing to talk about a granite whose fabric is clearly determined from the standpoint of rock classification and orogenesis than it is to speak of a granite whose fabric is unknown or only conjectured. Studies that are devoted purely to petrofabric problems (11, 13) would be of great value for the science of petrofabrics but are still seldom found in the literature.

Most papers deal with older geological problems. A great many of the papers consider orogenic problems and apply themselves particularly to the orogenic synthesis of the region under consideration. Geology needs petrofabric analysis not less than petrofabric analysis needs geology.

The summary of the literature shows clearly the success of the work and also what can be easily improved. In many studies the orientation of the diagrams in relation to geographical coördinates and to the fabric axes that are visible in the field is inadequate or not clearly presented. In some papers only the megascopic fabric (joints, schistosity, axes, etc.) is given, in others only the grain fabric. Both should be measured and presented together in their true orientation to each other. Some workers do not measure *all* the easily measurable minerals. Many others pay attention only to grain orientation and neglect other fabric data, especially the fine joints parallel to at least one of the *a, b, c* axes of the fabric. These joints can only be measured under the microscope and many of them are identical with megascopic joints. The relation of these microscopic joints to the grain fabric is more exactly determinable than the relation between megascopic joints and grain fabric. Valuable data are lost without a corresponding saving of time because too few partial diagrams are made. Much more attention should be paid than formerly to the distribution of the grains in a rock which form a given maximum in the diagram. This distribution is a deciding datum for many general problems, as, for example, the problem to what extent (in reference to what maxima) a mechanically induced orientation ("mechanical ruling") is determined by the mechanical behavior (translation planes, etc.) of the single grains or by the mechanical behavior of the whole fabric. Many of the problems referred to in (11) and (13) have not yet been dealt with in the current literature.

The formulation of the problems and the methods of investigation change from one case to another and can only be completely evaluated by using all the data at hand. Furthermore, petrofabric analysis can be applied to geologic problems only if one is quite familiar with the current state of the problems of petrofabrics.

Experience teaches that the progress of petrofabric analysis and its application to orogenesis must be the result of establishing types of a sufficient number of natural and artificial fabrics. It is advantageous to make a deductive summary of the data that have been obtained as long as such deductions and their application to geologic problems are not over-estimated. Walter Schmidt (13) has recently given such deductions for mechanical deformations in a manner stimulating for orogenic problems.

It is not possible to report here the whole content of such papers, although it might be possible to summarize them in a much shorter manner than the authors have done by the use of the fabric coördinates a, b, c and the correlated loci of the fabric planes designated by h, k, l as in crystallography. Only the results of importance for orogenesis will be emphasized here.

Crystallines of Southwestern Germany.—In the Böllsteiner Odenwald on the Rhine Doris Korn (5) made a petrofabric analysis as follows.—Megascopic fabric and grain fabric agree in their symmetry, the B-axes and the fabric symmetry (generally orthorhombic) are the same throughout the whole area, regardless of the different rock types and of the different tectonic units that were formerly assumed to be present. Some results of this work are:

1. Discarding of the older controversial orogenic hypotheses. These divided an area quite homogeneous in its fabric into genetically diverse units.
2. Obtaining of fabric data, which must form the foundation for every future orogenic discussion of the area.
3. Contribution to the descriptive characteristics of granitic rocks which in the Odenwald (Klemm, Bubnoff) and elsewhere were objects of futile genetic controversies as to whether they should be termed granite or gneiss.
4. In this area as in many others the megascopic fabric and the grain fabric (i.e. all the data of use for constructing the picture of movement or *Bewegungsbild*) show the same orientation in the granite and in the schist.

The work of Dr. Korn was followed by a series (8, 15, 6) of petrofabric analyses that not only show the inapplicability of the orogenic units formerly assumed but also afford important bases for new syntheses. Such bases are the symmetry of elastic and permanent deformation, the relation of elastic and permanent deformation to one another, the areas of homogeneous stress and strain, the relation between the movement-picture of the granitic bodies and of their envelopes, etc.

In the Bavarian Forest and Danube region petrofabric analysis has indirectly aided in solving orogenic problems (1, 2, 7) by its characterization of heterogeneous inclusions in granites and by supplying data on the older fabric inclosed by holoblasts. Maroscheck (7) showed the granite of Mauthausen to be a B-tectonite and explained its tectonics by petrofabric analysis. This method of analysis showed also the necessity of defining the joint systems by establishing their position relative to the *a, b, c* axes of the grain fabric. This necessity, always emphasized by petrofabric analysis, is often shown in the literature. For example, Sahlstein (10) recently established that the use of grain fabric is the only means of making a tectonic synthesis of the granulite area in Lapland. The misunderstanding that may arise by determining merely the position of megascopic planes without establishing the precise orientation of individual grains is very clear in the Drescher-Scholtz controversy (1).[5]

Nothhaft obtained results in the Bavarian Forest of general importance to petrofabric analysis by his studies of blastomylonites and he established essential tectonic features by the recognition and interpretation of B-axes.

Granulite analyses.—The work of Seng in Saxony (14) and Sahlstein in Finland (10) shows that of the types of granulite diagrams in (11) the most common are not those which exactly correspond to strongly deformed tectonites, such as shown for example by diagrams 38 and 26-28 in (11). On the contrary, the commonest granulite fabrics are quartz fabrics

[5] Scholtz maintained that the dioritic rock of Fürstenstein in the Bavarian Forest is an intrusive rock produced by magmatic differentiation. Drescher contends that the so-called diorite is in reality a hybrid rock resulting from the assimilation of paragneisses by a granitic magma. Scholtz cites in support of the intrusive origin of the supposed diorite certain joints that he interprets as cross (tension) joints formed above the intrusive conduit. Drescher shows by petrofabric analyses that these joints are not perpendicular to the axes of the grain fabric and therefore cannot be interpreted as cross (tension) joints. (Editor.)

of visible orthorhombic symmetry (11, D40-43) and having types of quartz maxima that are well-known also for other quartz tectonites. The possible relation of these quartz maxima to several distinct systems of fabric planes was suggested in (11) and was demonstrated by Rüger (9) for a Saxon granulite that showed two mutually perpendicular s-planes. We will try at Innsbruck to settle this problem by exact plotting of the manner in which the grains, having a defined position in the diagram, are distributed in a picture of the thin section. The opinions of Rüger (9) and Seng (14) agree with the opinions expressed in (11), in that paracrystalline deformed quartz fabrics may acquire an imprint (Aufprägung) as the result of even a very slight differential movement, as for instance the final imprint of some deformation. This possibility should also be considered for the Finnish granulites. In these granulites asymmetrically superposed fabrics argue against a complete reorientation and *therefore* against much tectonic transport. In Finland the next task will be to investigate whether *b* (B) coincides with the wide regional arc of the granulites and whether the symmetry plane (*ac*) stands vertical and parallel to the radii of the arc. If this proves correct, the Finnish granulites would be a normal axial mountain arc with the most common plane of symmetry and stress. The stress might be orthorhombic with slight differential movement, with or without transport in the direction of the radii of the arc. This problem will be discussed later by Sahlstein.

It will be seen therefore that there are many problems in granulite areas, some of general importance for orogenesis, which are to be investigated and to be solved only by means of petrofabric analysis.

Walter Schmidt, who has contributed much to the analysis of oriented fabrics, has also played an essential part in the application of fabric analysis to orogenesis. In one of the most important chapters on fabric analysis in (13) mechanical analysis is dealt with and applied theoretically to a typical Alpine orogenesis (Deckenbau).

Many of the deductions of W. Schmidt, but not all of them, agree with the facts and opinions of (11). Some opinions at variance with mine, which are of importance for orogenesis and which I will discuss elsewhere at more length, are:

1. The deduction that, unless a fabric is of mechanical origin, there is little possibility of making a definitive statement concerning it.

2. The separation of dynamics and kinematics in fabric analysis.
3. The deduction concerning mechanically induced orientation in fabrics of quartz and mica and the associated schistosity. Although these are based on special cases, they are given as general deductions.
4. The determination of the degree of anisotropy of rocks.
5. The treatment of some chief problems of the orientation of tectonites that are also discussed in (11). These problems are, whether we may consider a fabric as produced by rotation of individual grains or by rotation of the whole fabric in geometric relation to the deforming forces, and which maxima in a diagram are to be related to different fabric planes and which to different mechanisms of grain deformation.

These last mentioned problems especially are important for tectonics, for on their interpretation depends whether one may deduce from a tectonite diagram that deformation has occurred on one or on two sets of shear planes. These two types of deformation are of different tectonic significance; e.g., from a deformation having one set of shear planes it can be inferred that tectonic flow has occurred along a movement horizon (Bewegungshorizont), whereas from a deformation with two sets of shear planes it can be inferred that deformation took place "between more rigid jaws" or the two sets of shear planes can be interpreted as the final imprint of a compressive force produced by load. In contrast to the first type of deformation the latter type is not necessarily associated with much transport.

PROBLEMS OF IMPORTANCE IN THE RELATION BETWEEN PETROFABRICS AND OROGENESIS.

Petrofabric analysis is now being undertaken in America and I am convinced that American work will be of the greatest importance for its further development. Therefore I deem it better to call attention to the most recent development of some problems that are important for the relation of petrofabrics to orogenesis rather than to attempt any elementary introduction to petrofabrics (4).

Areas with steep and with slightly inclined or horizontal ("flach") B-axes.—In (11) I have distinguished the following two most important cases, with or without much transport.

The hand grips a rod "B" with greater pressure perpendicular to B, than parallel to B. This rod may be:

1, vertical (structure with steep axes) or
2, horizontal (structure with slightly inclined or horizontal axes), e.g., axial mountain structures with movements parallel to B and with or without transport perpendicular to B.
The B-axes may also have intermediate positions as, for instance, in some rocks in the Alps having triclinic fabric.

If we now give "B" all the characteristics of its megascopic fabric and grain fabric (11) and replace the hand by the area that surrounds the considered area containing B, we have one of the most important and most general distinctions possible to make in the deformed parts of the earth's crust, regardless of whether the deformation has been continuous or discontinuous.

The distinction between these two types of regions is decisively aided in its practical application by the modern knowledge of the relation between grain fabric and joint fabric and by the new criteria for the recognition and interpretation of B-axes, even where these are not recognizable in the field. The mere regional inventory of these B-axes would enrich the tectonic earth-picture and probably change it.

To-day it is possible to distinguish these two stress types by the fabric (joints or grain fabric or both) when the orientation of the fabric axes and of geographic axes have been exactly determined. This can be done even if other tectonic criteria can not be successfully used. It is often possible to work out the relation of these two stress-types to the crystallization produced by metamorphism, and by magmatic solidification, with a resultant gain in knowledge of the stress and strain that prevailed in definite environments of the earth's crust during rock formation of different types. Such stresses may result in tectonic transport or may produce tectonites *in situ*. Such tectonites are rocks showing evidence of movements that can be integrated to the general plan of movement, but which do not show much transport.

Investigation of the fabric often reveals "Stresstektonik" in the sense of (11). "Stresstektonik" includes the results of stresses comparable to the elastic stresses in the simple cases of physics. These elastic stresses occur sometimes at the beginning, sometimes at the end of greater permanent deformations, sometimes without any connection with permanent

deformation. These cases are distinguishable by modern petrofabric analysis as has been shown by examples. Such a study of the accessible earth's crust would serve to characterize its behavior better than would merely the solution of the tectonic problems in the narrower sense.

Ever since 1914 I have emphasized and illustrated the significance and abundance of structures with steep B-axes. Recently Schmidegg, of the Innsbruck Department of Mineralogy, has obtained the proof of such structure by field observation, by areal mapping, and by grain fabric analysis. This work demonstrates that the former interpretation of these areas as mere "Deckentektonik" does not explain the structure actually visible and shows that the divisions of the "Deckensystematik" are false. Schmidegg's results totally change the orogenic synthesis (12).

Thus, it is evident that it is of great importance to the solution of tectonic problems to search with the help of modern petrofabrics for areas with steep axes.

Types of folding and orogenesis.—One cannot draw the movement-picture of a folded region without considering in advance what types of folds it contains in reference to their differential movements (Teilbewegungen). Therefore it is necessary first to classify the folds by the criteria discussed in (11) and (13), which will be supplemented by other unpublished investigations. If one makes such a classification, one should not assume that shear-folding by slip along parallel planes is proved just because a tectonite-fabric of homogeneous folds made homogeneous by shear planes is present. It is quite possible to find a homogeneous imprint and preferred orientation (Regelung) imposed on folds of any origin. In such cases the folds are not formed by the shear planes of this imprinted movement nor must they necessarily have originated as shear-folds in a great tectonic transport (movement-horizon; "Decke"). It is also important in this connection that we investigated oriented quartz fabrics in tectonites that have not undergone much transport and that do show unrotated joints correlated with the orientation of the grain fabric produced by precrystalline deformation. Also of importance are orthorhombically symmetric quartz fabrics that have originated from the final imprint of the deforming force on rocks *in situ*. Such rocks, as for instance, some granulites and others, may have earlier undergone a tectonic transport.

Further, the preferred orientation of quartz in shear planes within single quartz crystals shows that quartz fabrics may have acquired this orientation by mechanical deformation (passive orientation) but without undergoing much transport.

This necessity for revising tectonic profiles was first and foremost emphasized by Walter Schmidt from some examples of Decken-structures in Switzerland. Several re-interpretations of details were made by Schmidt and he attempted to determine the broader features of the tectonic history of a typical Decken-structure. The fabric analyses have not yet been published.

One can show in a systematic way by fabric analysis and by more precise definitions that it is possible to replace the ambiguous dynamic hypotheses that have had a merely schematic representation in many tectonic profiles. This will often be of importance in orogenic syntheses.

Relation between preferred orientation and amount of differential movement.—A problem of great importance for petrofabric analysis itself as well as for orogenesis, and whose final solution needs much work, comprises the following two points:

1. The minimum amount of differential movement and deformation that can produce an oriented grain fabric. This amount is often, as in the case of quartz, very slight, particularly so where the deformation is paracrystalline.
2. The conclusion that can be drawn from an oriented fabric concerning the amount of the differential movements and therefore concerning the magnitude of tectonic transport. In general definitive conclusion is not yet possible.

A preferred orientation may be produced without tectonic flow during tangential transport. For example, strongly oriented B-tectonites can be formed "between moving jaws" without transport along a movement horizon. Often their deformation parallel to B may be even greater than the deformation perpendicular to B. There may be a lengthening (Dehnung) parallel to B or various types of shortening (Stauchung) parallel to B, including cross folding, due to inhomogenities. In addition we have studied in Innsbruck, limestones that do not show much transport, which have girdles, B-axes, and joints perpendicular to B (unpublished measurements by Ladurner on the Cretaceons limestone, Euganean Hills, Italy).

Often only the last chapter of the deformation can be inferred from the fabric. In other cases one can obtain by petrofabric analyses an insight into the earlier chapters also, including cases that show the imprint of more than one independent movement.

When the oldest fabric still perceptible in a rock has been determined, the history of the rock is deciphered as far as can be done by petrofabric analysis. If the geologist is interested in still earlier tectonic stages or in the magnitude of tectonic transport, there are other means of investigation. It is better to attempt no answer to such questions than to endanger the development of the fabric analysis.

To give to "load-metamorphosed" rocks an exact and practically determinable criterion one must apply a fabric-criterion. This criterion is the absence of any deformation fabric, even of the lowest degree determinable at present by fabric analysis. In such a case the rock has undergone loading without movement: It is purely "load-metamorphosed." Assuming constant volume, no fabric is known at present that can be ascribed to load without movement, i.e., without differential movement in the rock and hence without the development of tectonite-fabric. And if the term "load metamorphism" is applied to rocks having a low degree of deformation fabric, it is practically impossible to distinguish the metamorphism of these rocks from that of other tectonites.

The absence of deformation is not proved in all cases just because no preferred orientation is perceptible by optic or X-ray methods and because there are apparently undistorted features such as cross-bedding. This fact was discovered at Innsbruck by investigating the embedding limestone of distorted fossils and also by studying apparently undistorted cross-bedding.

In conclusion, it is possible at present to recognize tectonic movement on a large scale by comparison of several criteria of many well-characterized tectonites but not by consideration of oriented grain fabric alone.

Fusion tectonites (Schmelztektonite) and granites with oriented fabrics.—The fabric of solidified melts containing phenocrysts showed in many cases orientation according to grain shape (Regelung nach der Korngestalt), B-tectonites and S-tectonites oriented by grain shape. We have also described how the picture of the extrusive movement can be derived from the fabric, for example, in the quartz porphyry

in Saxony. M. Johs has recently dealt with similar problems (3).

In addition we meet again the old question, also of importance for orogenesis, of the relation in time between a parallel fabric in granitic rocks and the initial crystallization. Grain-fabric analysis leads to the following distinctions:

1. Granites that took on during their initial crystallization a fabric orientation similar to the fabric orientation of the inclosing rocks.
2. Granites that took on the same orientation as that of the inclosing rocks at a time later than the initial crystallization.
3. Granites that never took on the same orientation as the inclosing rocks or never took on any orientation in their fabric.

We know at present by grain-fabric analysis that typical granites whose texture has always been interpreted as the result of primary crystallization, such as the granite of Mauthausen in Austria studied by Maroscheck, may show the same grain-lattice orientation (Regelung nach dem Kornfeinbau) as rocks that were never molten. Therefore these granites have been subjected to conditions such that there has resulted an essentially or entirely similar portrayal of stresses and deformations as occurs in para-rocks.

Although we may not infer finally all the "portrayal" (Abbildung) and preferred orientation from the behavior of the single grain, nevertheless the preferred orientation of the grain fabric supplies the most intimate information we have concerning that behavior. The improved state of our knowledge at present is therefore as follows: There are granitic areas with constant symmetry of stresses. In these areas nearly the same conditions prevailed in granitic rocks and para-rocks. This is true both for the grain fabric which shows an older orientation inclosed by holoblasts, as well as for the grain fabric showing an orientation that was developed later. For these reasons we can speak either of "solidification" in the enveloping paraschists as well as in the granite, or else we should not use the word in either case. In respect to oriented fabric just as in mineral facies the difference between primary and secondary rocks vanishes at sufficient depth. Similar conditions are proved by like kind of orientation.

Likewise no boundary can be drawn by fabric analysis between plastic veinlike mylonites, blastomylonites, and fusion tectonites. These rocks cannot be distinguished by grain

fabric any more than they can be distinguished by intrusive or other criteria. Fabric analysis does, however, afford the information that genetic differences heretofore assumed do not exist; and the recognition of this very lack of genetic difference sheds light on conditions and processes.

The closer that the conditions prevailing in granitic fusion tectonites are approximated by other rocks, the more the grain-shape orientation of mica and the layering of the mica will be determined by slip along a single set of shear planes (einscharige Scherung) in the quartz-feldspar layers. This type of orientation may also occur in folds (13). This fact must be considered when interpreting folds in granitic rocks or in gneisses.

Depositional fabric (Anlagerungsgefüge) in Sediments.—As far as I know, no grain-fabric analysis of depositional fabrics has been published since (11). In connection with the general considerations of symmetry and grain-fabric analyses in (11) we have made in Innsbruck many optical and X-ray investigations of sediments. The new methods developed will be reported on elsewhere. Some results, in part of direct, in part of indirect importance for orogenic problems, are as follows:

I. I found in many cases that it is possible to determine and to interpret the anisotropy in the deposition plane as defined in (11). These determinations are made with special apparatus that allows rotation of the rock around the axes perpendicular to the deposition-plane in relation to oblique light whose angle of incidence can be varied. Such determinations may be of importance in orogenic and economic problems, if one wishes to reconstruct a picture of the depositing medium (streaming, etc.).

II. A second more extensive series of depositional fabric investigations dealt with limestones, dolomites, and limestone-dolomite rocks. They are chiefly Mesozoic Alpine sediments of either mechanical or chemical deposition, or superimposition of both, and with primary or secondary dolomite. Above all they show rhythmical systems of parallel planes which include layers whose thickness is of various orders of magnitude that are superimposed on one another in the same rock exposure. The thickness of the layers was determined by many hundreds of field and laboratory measurements. I consider the description and interpretation of these rhythmical systems to be just as important for orogenesis in the wider sense as tectonic studies.

Many of the deductions given in (11) are applicable to the description of these rock fabrics. Furthermore, by applying other methods more information in some respects could be obtained from the micro-fabric of these rocks than from the micro-fabric of tectonites, as, for example, information concerning internal erosion and deposition (interne Abtragung und Anlagerung) in the micro-fabric and the determination of top and bottom at the time of rock formation.

Grain-fabric analyses were made from homogeneous limestones and dolomites and also from typical homogeneous areas inclosed by inhomogeneous limestone and dolomite. The investigation of the inhomogeneous rocks gives better results the more carefully one selects the places in them to be studied. Such places should be: 1, defined as to genesis; 2, homogeneous in the particular areas exposed to the X-rays in each film or in the area comprised in thin section; and 3, defined in respect to their distribution and volume in the rock.

Study of the grain fabric of calcitic and dolomitic sediments disclosed:

1. Numerous fabrics of random arrangement in widespread rock types.
2. Several orientations determined by growth (Wachstumsregelungen) which are well defined and as a rule easily distinguishable from the characteristic orientation of tectonites. These growth-orientations may be present as partial fabrics (Teilgefüge), ranging from small up to very large parts of the rock.

These fabric analyses have contributed to the solution of the following problems:

1. The genetic interpretation of certain rhythmical beddings.
2. The more exact differentiation of calcareous sediments from one another.
3. The differentiation of undeformed calcareous sediments from calcareous tectonites by means of grain fabrics.
4. Early paradiagenetic movements in the environment of sedimentation.
5. Distinction between top and bottom at the time of rock formation by means of various and abundant "geopetal" fabrics.

Examples will be given elsewhere.

In order to avoid possible duplication I take this opportunity of enumerating the following unpublished work done in the

Innsbruck department, grain-fabric analyses of calcareous sediments by Ladurner and Felkel, gypsum by Fairbairn, corundum by Reithofer, and crystalline schists by Schmidegg.

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METAMORPHOSED CALCAREOUS CONCRETIONS AND THEIR GENETIC AND STRUCTURAL SIGNIFICANCE.

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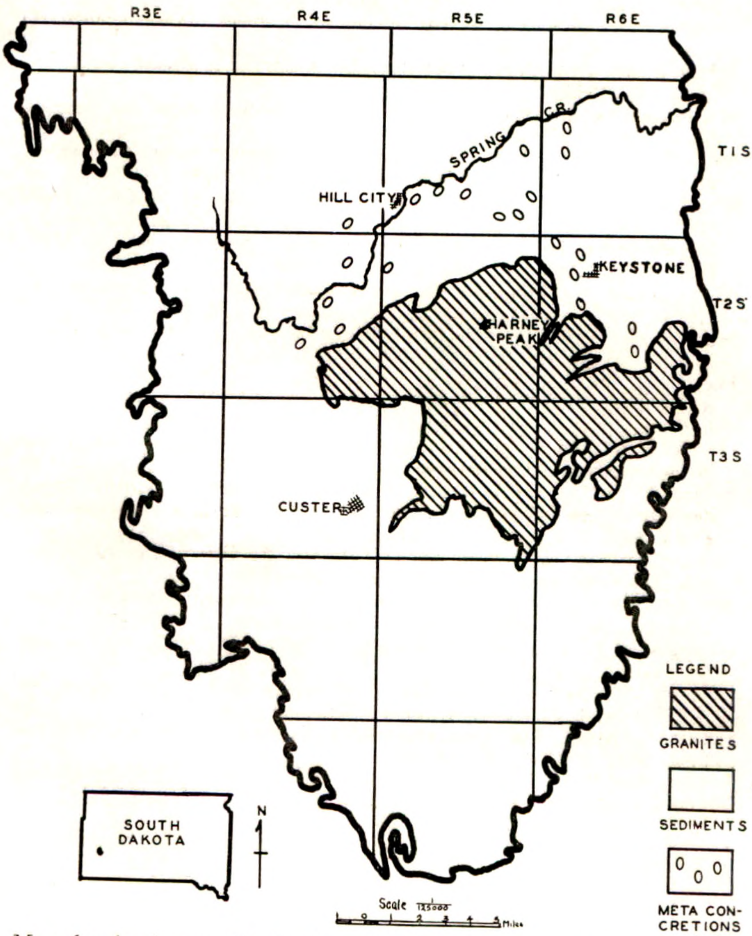
OCCURRENCE.

Within the younger pre-Cambrian sediments of the Black Hills lying northwest, north, and northeast of the Harney Peak



Map showing known distribution of ellipsoidal meta-calcareous concretions in the pre-Cambrian sediments of the Southern Black Hills. Outline of granite area from U. S. G. S. Folio No. 219.

Granite area occur many triaxial ellipsoidal masses of lime plagioclase-grossularite-diopside-quartz rocks. So far as noted

1

2

Fig. 1. Ellipsoidal meta-calcareous concretion.
Fig. 2. Cross section of a concretion cut normal to the major ellipsoidal axis.

these ellipsoidal masses occur only in beds of siltstones now metamorphosed to quartz-feldspar-biotite schists. The stratigraphic range of the ellipsoids seems to be through several thousand feet of beds. The sedimentary formations in which they occur contain a few dikes and sills of pegmatitic granite throughout, but have been observed to contain basic intrusives only in the lower part of the sequence at some considerable distance from the ellipsoids.

GENERAL DESCRIPTION.

A majority of the ellipsoids range in size from that of a small cocoanut to that of a thick bed pillow. Some are elongated to the extent of being cigar-shaped, while most have approximately the shape of a somewhat flattened watermelon (Fig. 1). A majority have the form of a triaxial ellipsoid with the long and intermediate axes in the plane of flow cleavage. The major axes lie in approximately parallel position throughout considerable areas. The average ratios of the lengths of intermediate to short axes is about three to two, while the long axes range from five to as much as fifteen on the same scale.

Besides the ellipsoids lenses of rock of similar composition but of much greater size occur within the same sedimentary beds. A few vein-like masses of the same rock cut bedding planes.

In cross section the ellipsoids show clearly defined concentric banding consisting generally of two prominent zones and in some specimens as many as five prominent ones (Fig. 2). A few of the smaller ones have nearly equal minor and intermediate axes and show only a very ill-defined concentric banding. The two most prominent zones in a great majority of the ellipsoids include an inner core composed of crystals possessing no parallelism in orientation and an outer zone with plane and linear cleavages well developed. In the central cores of a few ellipsoids a slight tendency toward parallelism of elongation of the first formed minerals was noted, but in most cases if such a structure ever existed it has been obliterated by recrystallization. Intermediate zones are marked by differences of mineral composition rather than by differences of structure, and in general are not foliated.

Usually the ellipsoids are much more resistant to weathering than the enclosing rocks and protrude from their matrix or form surface residual boulders.

PETROGRAPHY OF THE ELLIPSOIDS.

Inner Cores.

Rounded to subangular quartz grains averaging about .170 mm. in diameter comprise from twenty to forty per cent of the interiors of most of the ellipsoids. In some cases the quartz grains are slightly elongated in approximately parallel positions giving the ellipsoid a rude foliation. Few of the grains show sutured texture or strain-shadow effects. These quartz individuals are regarded as approximately, but not identically, the original grains of a siltstone.

Surrounding the quartz and forming with it a mortar structure occur smaller, nearly equidimensional grains of lime-rich plagioclase making up an average of about forty per cent of the core. These grains average about .08 mm. in diameter. The larger grains exhibit albite twinning but a majority of the smaller ones do not. Small rounded quartz grains occur as inclusions in many of the larger grains of plagioclase. The minimum index of refraction of the latter is always greater than the maximum for quartz, and the mineral shows a strong relief against the quartz. All grains studied were optically negative, had an optic angle of eighty degrees, and a maximum extinction angle in the zone normal to 010 of a little over forty-five degrees, measured from the fast ray to the albite twinning lamellae. Their composition is therefore approximately An_{85}.

Pyroxene comprises a total of probably less than ten per cent of the interiors. It occurs as small grains a fraction of a millimeter in diameter in areas of plagioclase between quartz grains, also as cellular anhedral crystals as large as two or three millimeters diameter. The diopside is poikiloblastic, enclosing rounded grains of quartz, some clinozoisite, and plagioclase. Branches of the larger masses extend outward from centers of growth to penetrate plagioclase areas and finally enclose quartz grains, the latter becoming smaller as the pyroxene increases in amount. The pyroxene clearly replaces and is later than plagioclase and quartz. Macroscopically the pyroxene is light green and exhibits good prismatic cleavage. In thin section it is colorless and shows a marked relief against quartz and plagioclase. The maximum index is above and the minimum index below that of clinozoisite, the index of which is approximately 1.72. It has a maximum birefringence of about .030, an optic angle of sixty degrees, an extinction angle from Z to c

of nearly forty-five degrees, and is optically positive. It rarely exhibits crystal boundaries or twinning. It is probably a somewhat aluminous diopside low in iron.

Light-pink garnet in grains from a fraction of a millimeter to three or four millimeters diameter occurs in somewhat

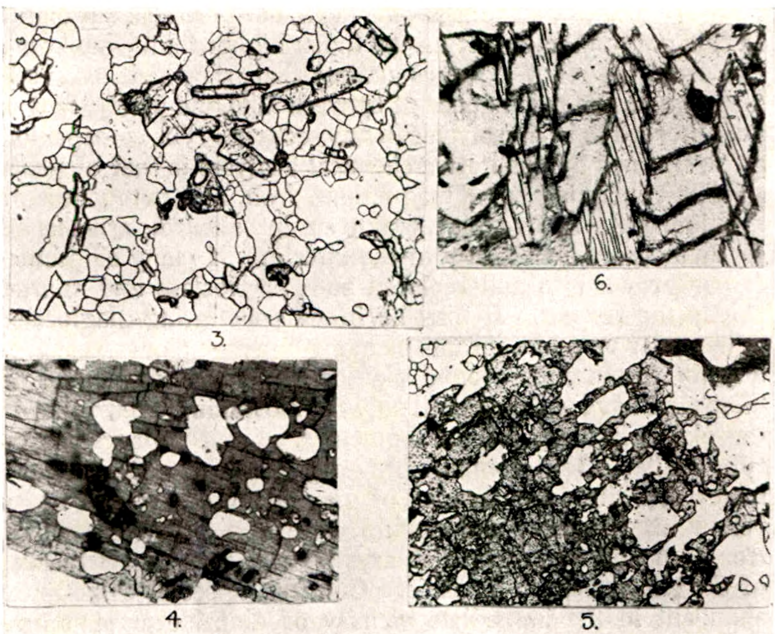


Fig. 3. Quartz and Bytownite partially replaced by Clinozoisite.

Fig. 4. Diopside containing rounded grains of clear quartz and dark grains of titanite.

Fig. 5. Garnet showing elongation with schistosity and including quartz. A little feldspar occurs outside the garnet area.

Fig. 6. Garnet partially replaced by hornblende.

greater abundance than pyroxene. It possesses much the same relationship to quartz and plagioclase as does pyroxene. The smaller grains are to be found in areas of plagioclase between quartz grains, and the larger anhedral to euhedral grains enclose quartz poikiloblasticly. Clinozoisite and plagioclase are rarely found as inclusions in garnet, whereas areas surrounding the garnet are usually void of these minerals and contain only quartz. Inclusions of diopside in elongated forms but in parallel crystallographic position are somewhat radially

arranged in a few garnet crystals. These orientations are believed to be due to radial replacement of diopside by garnet, rather than the replacement of garnet by diopside. In most cases the two seem to have grown simultaneously but the garnet continued its growth later than did the diopside. Garnet is clearly younger than plagioclase and quartz and grew simultaneously with, or somewhat later than, most of the clinozoisite. In thin section the garnet has an index higher than clinozoisite and from the relief it shows against that mineral it was estimated to have a refringence of between 1.74 and 1.76. It was not observed to be anisotropic in any section. The composition as determined by qualitative chemical analyses is that of grossularite containing some magnesium, iron, and manganese.

Clinozoisite in irregular grains or in euhedral lath-shaped crystals occurs abundantly in the interiors of many ellipsoids. It has grown into and replaced both plagioclase and quartz, chiefly the former. It may be found penetrating plagioclase in irregular vein-like sprouts or along cleavage planes. It frequently forms rims around plagioclase grains, and some of these rims have widened until only the most minute remnants of the plagioclase are left in the center. Centers of grains of clinozoisite often contain brownish-gray almost isotropic material, while the outer rims of the mineral have a first order yellow birefringence and contain more iron. This zoning of iron-poor and more iron-rich crystals was noted in inclusions of the clinozoisite in diopside. Clinozoisite seems to be more abundant in the immediate vicinity of diopside crystals and perhaps even more so where the latter is partially bordered by actinolite or hornblende and where apatite is abundant. In rocks similar in mineral content to the ellipsoids but not possessing their forms, clinozoisite appears to have developed directly from calcite. In at least one of the ellipsoids the clinozoisite has been somewhat elongated in the direction of foliation. As a general rule this mineral is less abundant in the outer sheared portions of the ellipsoids than in the nonfoliated interiors. From the data it would seem probable that the clinozoisite grew largely under the same conditions as did diopside and garnet, that is, under high temperature and uniform pressure, but that the high temperature and the chemical environment were more important than the conditions of pressure. In thin section the clinozoisite is colorless and has a marked relief against quartz and plagioclase, but not against

diopside and garnet. It gives a low first order, anomalously bright blue interference color, and shows excellent cleavage with inclined extinction.

Titanite occurs rather abundantly in small somewhat rounded to irregular grains and rarely in euhedral crystals as inclusions in quartz, plagioclase, diopside, garnet, and clinozoisite. In some occurrences cracks radiate from titanite grains. It also occurs as euhedral crystals in veins cutting the above-mentioned minerals in other rocks of a similar character found in this region, especially in the vicinity of granites. Because of these facts it is considered to be a late mineral derived in part, at least, from the granite.

Pyrite, pyrrhotite, magnetite, apatite, and rarely tourmaline, appear to be more abundant near the granite and are likewise believed to be late minerals. Chlorite has been observed to replace garnet and diopside while sericite replaces plagioclase. A few diopside grains are bordered by small amounts of actinolite.

The Outer Zones.

Concentrically around the central core occurs usually an outer zone of thickness varying from one to three inches with somewhat different and highly important characteristics. In the outer zone quartz and plagioclase occur with the same mortar structure as in the inner cores. The texture is often finer, distinctly granulitic, and foliated. The plagioclase is of the same composition, An_{85}, as in the inner zone but twinning is less pronounced.

The garnet of the outer zone resembles that of the inner in color and index of refraction. It is less cellular and shows better developed crystal faces. Some of it is distinctly elongated in the plane of foliation. Clinozoisite appears to be slightly more iron-rich in the outer zones but is relatively rare.

So far as observed pyroxene is entirely lacking, its place being taken by light-green poikiloblastic hornblende containing rounded quartz grains and less often plagioclase or clinozoisite. The hornblende occurs for the most part in sub-parallel development but occasionally it has a decussate arrangement. No direct evidence that hornblende had replaced diopside in this zone was noted, but in closely allied calcareous siltstones in the region it clearly has done so. In bands of the middle zone it

has also been found to fringe and replace diopside. The hornblende in thin section is yellowish-green parallel to X, and bluish-green parallel to Z, its extinction angle from Z to c is 18°, the optic angle is about 80°, and the birefringence approximately .020. It contains a few small inclusions surrounded by pleochroic halos. These inclusions are pleochroic in brown and green, have a positive elongation, and a low birefringence; they are believed to be allanite.

In the outer portions of the outer zone and in the enclosing siltstones, brown biotite is abundant. The biotite conforms for the most part to the foliation exhibited by the rock as a whole. In a few cases in which the hornblende is not oriented the biotite likewise is not. Euhedral zircon occurs in the biotite as inclusions surrounded by pleochroic halos.

In some cases a zone rich in pyroxene and poor in garnet was observed between the two zones described above. In others hornblende was noted in the intermediate zone partially surrounding and replacing poikiloblastic diopside.

CHEMICAL COMPOSITION OF THE ELLIPSOIDS.

The following is a partial chemical analysis of the central core of an ellipsoid.*

Analysis of the inside of an ellipsoid.

SiO_2	58.30%
TiO_2	.50
Al_2O_3	22.99
Fe_2O_3	.74
FeO	1.00
MgO	1.51
CaO	14.00
MnO	.20
H_2O+	.29
H_2O-	.08
Na_2O	n.d.
K_2O	n.d.
	99.61%

The three significant features are the high silica, alumina, and lime content. Iron, manganese, and alkalis are low. Magnesia is well represented but not high. Study of the hand specimen and thin sections of the rock from which the analysis was made indicates that the ellipsoid is made of approximately

* Analysis made by H. Benninghoff of the Chemistry Department of the State University of Iowa.

20 per cent quartz, 40 per cent An_{85}, 30 per cent grossularite, 10 per cent diopside, and small amounts of titanite and clinozoisite. The chemical analysis is entirely in harmony with the mineral analysis.

ORIGIN OF THE ELLIPSOIDS.

The ellipsoids have originated from nodular, concentrically banded material occurring in the siltstone beds of the younger pre-Cambrian of the region. The siltstones contain chiefly quartz, biotite, and alkali feldspars, including both orthoclase and plagioclase, some muscovite, titanite, apatite and sulfides, and in places tourmaline of secondary origin. No plagioclase as rich in lime as An_{85} has been observed in the schists. Neither has clinozoisite nor diopside been found. The siltstones have a very well-developed schistose structure which is generally lacking in the interiors of the ellipsoids. The mineralogy of the limestones and quartzites of the region is quite different from that of the ellipsoids both where locally metamorphosed at contacts with granite and elsewhere. Metamorphosed clay beds are now micaceous, quartzose schists and are quite different from the ellipsoids.

The mineralogy and textures of beds that were once highly calcareous siltstones are quite similar to the same features of the ellipsoids. The calcareous siltstones occur as thin beds and lenses interstratified with non-calcareous siltstones and with metamorphosed shales. The minerals include abundant calcite, quartz, lime-plagioclase, hornblende, lime-garnet, clinozoisite, and considerable titanite, with some diopside, biotite, chlorite, muscovite, and sulfides. In some cases quartz and plagioclase have the same mortar structure and garnet and hornblende contain quartz, plagioclase, and clinozoisite poikiloblasticly, as in the ellipsoids. The chief differences to be found in the calcareous siltstones are the abundance of calcite, the lack of diopside, a well-developed foliated structure, and the fact that clinozoisite develops directly from calcite.

From the high silica, alumina, and lime content of the ellipsoids, their universal occurrence in beds once siltstones, their similarity in mineralogy to the known calcareous siltstones, their uniformity over a wide area, and from their shapes and concentric banding, the ellipsoids are believed to have originated from calcareous concretions embedded in argillaceous siltstones.

That they were not conglomerate boulders is clear from their uniform composition and structure over a wide area. Dynamic breccias containing somewhat rounded and elongated masses are to be found in the region, but these contain the same materials as the enclosing sediments, whereas the ellipsoids do not. The chemical composition of the ellipsoids approximates that of a quartzose anorthosite. A magma of this composition might have been intruded into the siltstones and might have formed ellipsoidal shapes during folding. An igneous rock of this composition is extremely improbable and there is no apparent reason why one should always occur in siltstone beds. Magma intruded in such amounts should frequently be found cutting bedding planes. Such is not the case.

The major and intermediate axes of the ellipsoids are parallel to the axial planes of the folds. The shaping of the ellipsoids is therefore believed to have taken place during the folding of the sediments. Some schistosity was probably developed in them at this time. That they may have developed an elongated form during concretionary growth is of course possible, but it would be rather remarkable that the axial planes of later folds should have been developed parallel with the original growth of concretions.

The reshaping of the ellipsoids was followed by a period of high-grade metamorphism under great uniform pressure and attended by high temperatures, probably in the van of an approaching magma. The quartz, clay, and calcite were recrystallized into an aggregate of quartz, plagioclase, diopside, grossularite, clinozoisite, and possibly titanite and sulfides. At this stage the original cleavage was largely obliterated. Some was preserved in the minerals that were not destroyed and some by replacement of the foliated structure.

At a later stage the ellipsoids were again subjected to an unequal pressure with the advent of the oncoming magma, or the advance of a second magma, and a new series of minerals were developed in the outer zones characterized by oriented hornblende and biotite and to a lesser extent garnet and clinozoisite. The pre-existing quartz and plagioclase were granulated, the diopside was destroyed, and the garnet flattened and recrystallized in this zone. These alterations seem to have been accompanied or followed by the introduction of solutions from the magma bringing titanite, apatite, and sulfides, and during their waning activity developing chlorite and sericite.

One of the striking features of the later metamorphism is

the fact that the differential pressure causing recrystallization to form hornblende and biotite, was either not transmitted in sufficient intensity to the interiors to cause alterations or the penetration of some catalytic agent such as water was not sufficiently deep to cause them. Another interesting fact is that the plane and linear cleavages developed during this later stage are in many cases not parallel to the elongation of the ellipsoids. This clearly shows a change of direction of the later applied forces.

Metamorphosed concretions have been described by Keith[1] in the Ducktown district, Tennessee, where he noted ellipsoidal structures in the Lower Cambrian sediments. At first he called these diorite but later proved them to be metamorphosed sediments. In 1926 Laney[2] studied the nodules in greater detail through the use of thin sections. He applied the name pseudodiorite to them because of their chemical composition and their resemblance to an igneous rock. He stated that the rock occurs in the greywacke in three forms: (1) as dikes; (2) as pipe-like bodies with circular cross section; and (3) as ellipsoidal bodies from a few inches to two feet in diameter. The structures are concentrically banded with eight or more layers in some cases. He noted that although the graywacke is schistose, the ellipsoids are not and they show no orientation of minerals. With regard to them he concludes:[3]

"It is therefore believed that because of an original difference in composition, probably a concentration of calcium carbonate in the form of calcite, the material of the pseudodiorite was completely crystallized under static conditions of high pressure and high temperature, very soon after the schistosity developed.

"The fact that nearly all the pseudodiorite carries larger quantities of calcite than the surrounding rock, taken in connection with the close resemblance of the pseudodiorite in form and mode of occurrence to the calcareous concretions in sandstones, leads to the conclusion that it is the metamorphosed equivalent of such concretions.

"The mode of occurrence, and the features of the pseudodiorite as revealed by the microscope, as well as the chemical analyses of the rock, all preclude the idea that it is of igneous origin. The pseudodiorite is confined to rocks that have suffered intense metamorphism. In the less metamorphosed rocks there are numerous

[1] Keith, Arthur, Production of Apparent Diorite by Metamorphism, Bull. Geol. Soc. of Amer., vol. 24, pp. 684-685, 1913.

[2] Emmons, W. H., and Laney, F. B., Geology and Ore Deposits of the Ducktown Mining District, Tennessee, Prof. Paper, No. 139, 1926.

[3] Emmons, W. H., and Laney, F. B., Idem., p. 20.

ellipsoidal and irregular concretions, which, so far as form and manner of occurrence go, are entirely similar to the pseudodiorite. In fact, in some of the areas where the rocks have been subjected to only moderate metamorphism, calcareous concretions have been found which still retain their normal appearance but in which some of the minerals so characteristic of the pseudodiorite have been developed."

In finding the unmetamorphosed concretions with which to compare the metamorphosed equivalents Laney was more fortunate than the authors. Laney makes no mention of a mortar structure of quartz and feldspar, nor of a poikiloblastic texture of amphibole, pyroxene, and garnet that is so characteristic of the Black Hills concretions. In abundance Laney finds the minerals to range as follows: quartz, plagioclase ranging from albite to labradorite, orthoclase, hornblende, biotite, calcite, zoisite, muscovite, garnet, sulfides, and titanite. In the Black Hills concretions, no albite or orthoclase has been found and the plagioclases are as basic as bytownite. Laney does not mention an orientation of the structures or minerals with regard to schistosity, linear cleavage, or to the axes of folds.

Although the similarities are great between the Ducktown concretions and the ellipsoids from the Black Hills, the mineralogy and textures of the latter are sufficiently unique to warrant description. Also, the genetic significance of the textures is important, and has not been emphasized in the case of the former. Laney gave no order of formation of minerals except to state that biotite is apparently later than green hornblende. While he finds as much as 25 per cent calcite in the Ducktown rocks, only a very few minute grains of calcite have been noted in the Black Hills ellipsoids.

STRUCTURAL SIGNIFICANCE OF THE ELLIPSOIDS

It is now quite clear that there are at least two granites of pre-Cambrian age within the area, an older rather fine-grained, foliated, gray granite and a younger coarse-grained largely unfoliated pink granite with numerous related pegmatites. Both are probably younger than the latest pre-Cambrian sedimentary formations of the southern Black Hills.

The pre-Cambrian sedimentary formations northwest of the Harney granite area have been deformed into nearly recumbent isoclinal folds probably accompanied by low angle overthrust faults of the nappe type. In this area the dip of the

axial planes of the folds is at low angles toward the northwest away from the central granite area and the pitch of the axes is at low angles to the southwest. The late pegmatitic granite was intruded into this folded structure.

It was formerly thought that the granite had invaded a gently folded series because of the low dips of the sediments bordering the granite area and the low dips of the xenoliths of the same rocks within the granite.[4] It now appears that this interpretation is probably in error as originally suggested by Van Hise.[5]

Throughout the area in question the direction and amount of pitch of many folds were measured and the pitch of the major axis of many ellipsoids within the same rocks was determined. A close parallelism between the two was found, the ellipsoids pitching southwest at low angles with the fold axes.[6] Within the ellipsoids, however, the plane and the linear flow cleavages frequently intersect the plane of the major and intermediate axes of the ellipsoids at angles of as much as 20°, indicating that later recrystallization under differential pressure took place under stress applied in different directions from those that shaped the ellipsoids. Consistent with this idea is the fact that many cases of a late flow cleavage intersecting and partially obliterating an earlier one have been noted elsewhere in the region.

In harmony with the history and structure recorded by the concretions, the granites, the folds, and the cleavage, the following statements may be made. The thick series of sedimentary formations in the area were intricately folded and faulted, forming structures of the nappe type. The high temperatures developed after a magma had come to its final position and the differential pressures had been relieved, caused recrystallization of the rocks, resulting in new minerals of a type consistent with the new environment. The advance of a second magma developed new conditions of differential stress not entirely parallel with the earlier stresses and a new flow

[4] Runner, J. J., The Mechanics of Intrusion of the Harney Peak Batholithic Granite, Bull. Geol. Soc. Amer., vol. 39, p. 186.

[5] Van Hise, C. R., The pre-Cambrian rocks of the Black Hills: Geol. Soc. America Bull., Vol. 1, p. 241.

[6] The pitch of the major axes of many conglomerate boulders elongated by pressure, in the pre-Cambrian of the Nemo district and the pitch of lenses of quartz in the cummingtonite schists of the Rochford and Lead districts have likewise been observed to be in the same direction and at least very nearly parallel to the pitch of the folds in those areas.

and linear cleavage was developed at an angle to the earlier one, partially obliterating it. The second magma crystallized into the well-known Harney pegmatitic granite. It is worthy of note at this point that if this interpretation is correct the earlier structures of the sediments did not entirely determine the structure of the late granite nor did the direction of pressure produced by this granite determine the structure of the sediments. In other words the late plane and linear flow cleavage can only be used to determine the character of the later deformation produced by the force of intrusion of the late pegmatitic granite. This cleavage does not give a true picture of the preëxisting structures except in so far as these structures determined or directed the flow of the granite. In many cases the two sets of structural lines may be parallel but in others there is a considerable difference between them.

If the history of the ellipsoidal concretions has been as outlined above, then they furnish an invaluable aid in determining the character of the earlier and later structures. The dip of the plane of their major and intermediate axes and the pitch of the major axes give the dip of the axial planes and the pitch of the axes of the earlier folds respectively, while the dip of the plane cleavage and the pitch of the linear cleavage in the outer zones of the ellipsoids will determine the same for the later folding.

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ELECTRICAL PROFILES IN GAPS IN NEW JERSEY TRAP RIDGES.

M. KING HUBBERT.[1]

In the Passaic quadrangle of New Jersey are three basalt lava flows, commonly spoken of as trap rock. These occur conformably interbedded with the Newark red-beds of Triassic age. The first two flows in the order of their ages are known respectively as the First and the Second Watchung Mountains. The third and youngest flow outcrops as a series of low hills bearing the names in the order of their occurrence from south to north of Long Hill, Riker Hill, Hook Mountain, and Packanack Mountain.

The two Watchung Mountains form conspicuous topographic ridges standing about 400 feet in elevation above the surrounding lowlands. These ridges dip roughly 12 degrees to the westward and exhibit steep escarpments to the east and gentler dip slopes to the west. The hills of the third trap ridge are less conspicuous, being more narrow and also rising only 200 to 300 feet above the surrounding area.

In each of these ridges there occur two conspicuous gaps (Fig. 1). The northernmost gaps in the First and Second Mountains are located near Paterson. The southernmost gaps are near Milburn. In the third ridge the two gaps occur respectively to the north and to the south of Riker Hill.

In the Passaic Folio of the U. S. Geological Survey the trap rock is mapped as being continuous across all four of the gaps in the First and Second Mountains. In the gaps of the third ridge, however, the trap rock is mapped as being non-existent.

Johnson[2] has tabulated the field and well log data regarding the occurrence of the trap rock in each of these gaps. In the Paterson gaps of the First and Second Mountains the presence of trap is known from surface outcrops and from well logs. In the gap north of Riker Hill there are no outcrops and no well logs to trap rock. In the gap south of Riker Hill Johnson records 9 well logs showing the elevation of the trap to range from 77 to 141 feet, or an average of about 115 feet above sea level. The surface elevation in this gap is about 200 feet.

[1] The writer is indebted to Mr. A. N. Labounsky for assisting with field work and computation and to Prof. Douglas Johnson for advice and criticism.

[2] Johnson, Douglas, Stream Sculpture on the Atlantic Slope. Columbia University Press, pp. 112, 1931.

In the Milburn gap of Second Mountain there are no data. For the Milburn gap of First Mountain Johnson gives well logs showing elevations of 0, 0, and 113 feet.

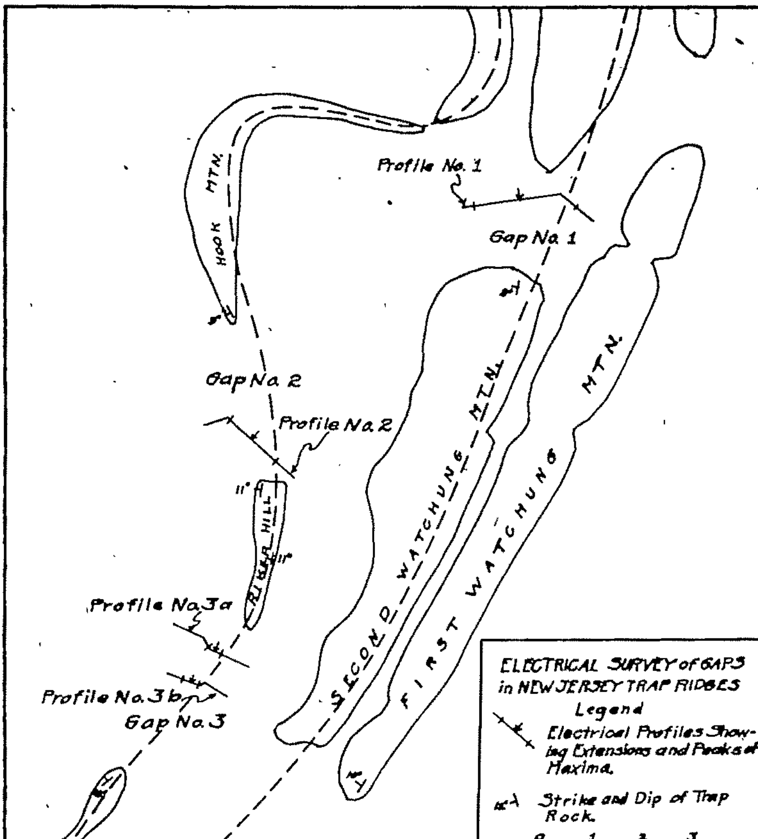

Fig. 1. Map of part of Passaic quadrangle showing the location of gaps in trap ridges and of the earth resistivity profiles. The marks on each profile line indicate the location of the maxima and of the extent of the resistivity "high."

These gaps are of pre-glacial origin, and all contain glacial debris at present. Four of them, both those in the third ridge and the Paterson gaps of the First and Second Mountains, are at present occupied by the Passaic River which is dispropor-

tionately small as compared with the gaps it occupies. It is besides consequent upon the glacial topography.

Johnson[3] has recently reopened the question of the origin of these gaps and has advanced the hypothesis that they represent a former course of the Hudson River. On this hypothesis the trap should presumably be continuous across all the gaps, even where concealed by glacial and stream debris covering the floors of the gaps. Davis earlier suggested a history of capture, which as Johnson shows would be favored by the complete absence of trap in certain of the gaps, a condition quite compatible with present topography on the assumption that the lava flows were not everywhere continuous over this region. As the presence of trap at all the gaps would render the Davis theory of capture more difficult to apply, it becomes a matter of some importance to determine the critical facts.

Such determination is favored by the exposure of trap at a few places in the floor of one gap nearly covered by debris, and by the known presence of trap in others as revealed by well borings. It is accordingly possible to make geophysical observations at these gaps, to determine to what extent the presence of the known trap will affect measurements of earth resistivity. Corresponding measurements at gaps where the presence of the trap is not known should then reveal whether its absence there is real or apparent. It also would have been important to determine depths to bed-rock but unfortunately the apparatus was not that most suited for that purpose.

EARTH RESISTIVITY PROFILES

The present work was undertaken in the spring of 1932. Earth resistivity profiles (Fig. 1) were run in three of the six gaps: one in the Paterson gap of Second Mountain, one in the gap north of Riker Hill, and two in the gap south of Riker Hill. Unfortunately, the combination of marshes and building structures made it impossible to obtain other needed profiles, especially in the Milburn Gaps.

The apparatus used was that known as the Megger Ground Tester.[4] The field technique employed was the four electrode

[3] Op. cit., pp. 90-131.

[4] Hubbert, M. King, Results of Earth Resistivity; Survey on various Geologic Structures in Illinois. A. I. M. M. E. Tech. Pub. No. 463, pp. 5-7, 1932.

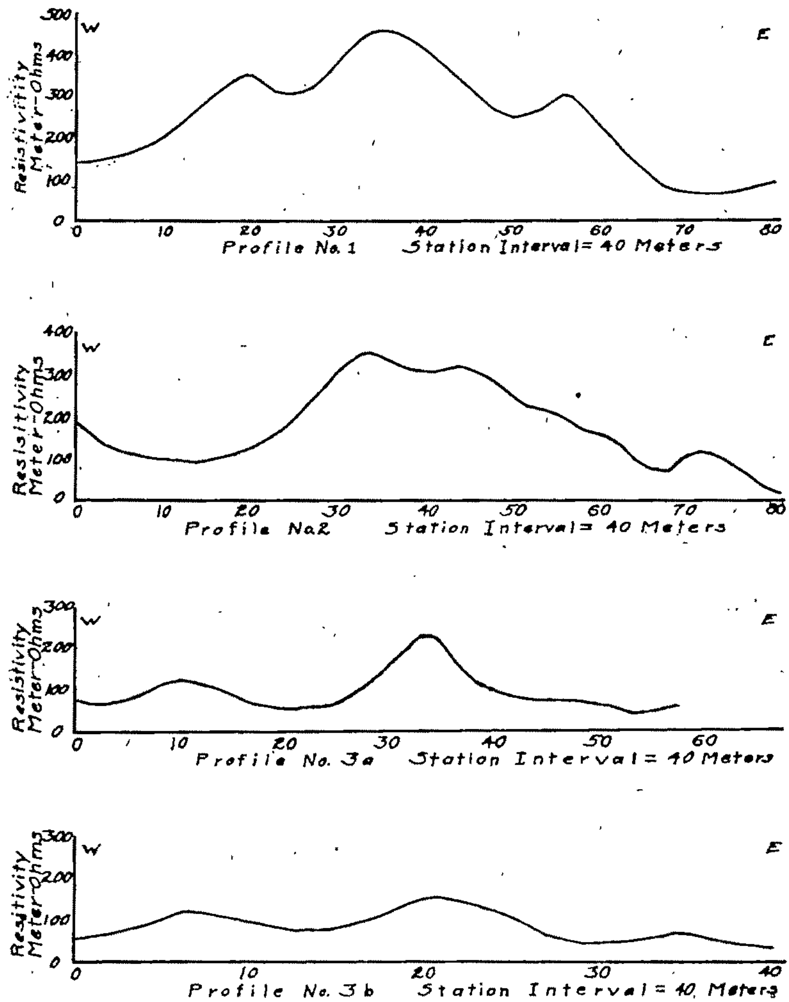

Fig. 2. Graphs of the resistivity profiles. The abscissas are distances plotted by station numbers. Each number represents 40 meters. The ordinates are resistivity in meter-ohms.

method devised by Wenner[5] and applied by Gish and Rooney.[6] In all of the present work the electrode spacing was kept constant at 40 meters and stations were occupied along the line of traverse at intervals of 40 meters. The values of apparent specific resistivity obtained were, therefore, those due principally to the rock contained within the layers above a depth of 40 meters.

Rocks of non-metallic minerals when free from water are highly resistant to the flow of electric current. The conductivity of such rocks under normal conditions is due almost entirely to their water content. Sundberg[7] has shown that if the conductivity of the impregnating water is unchanged, the conductivity of the rock increases with the increase of pore space and water content in water-saturated rocks.

In the present instance it was assumed that the Newark red-beds were more porous than the basalt. The work was carried out during the wet season and the water table at the time was practically coincident with the surface of the ground. Therefore, it was expected to obtain relatively low values of earth resistivity in those places where the earth materials to a depth of 40 meters consisted of glacial drift and of red-beds. Should the trap rock protrude into this zone, however, it was expected that the values of resistivity obtained would be somewhat higher. Accordingly, if a resistivity profile were taken through one of these gaps transversely to the strike of the trap ridges, the resistivity curve so obtained should begin low, rise gradually to a maximum as the buried trap is crossed, and then decline as the less resistant rocks again become dominant.

With this in view the four electrical profiles shown in Fig. 1 were taken. Fig. 2 shows graphically the results obtained in each. The graphs in Fig. 2 are the running means obtained by plotting at each point the averaged values of the five nearest stations. This served to emphasize the broad features of the curves and to iron out the distracting, erratic, smaller fluctuations. It will be noted that in each of these resistivity profiles there occurs one principal maximum. In Fig. 1 is indicated the approximate extent of this principal "high" and

[5] Wenner, F., A Method of Measuring Earth Resistivity. U. S. Bur. Stds. Bull. 258, 1916.

[6] Gish, O. H., and Rooney, W. J., Measurement of Resistivity of Large Masses of Undisturbed Earth. Terrest. Mag. and Atmos. Elec. 30, pp. 161-188, 1925.

[7] Sundberg, Karl, Principles of Swedish Geo-Electrical Methods. Gerland's Beitraege Supp. Applied Geophys., 1, No. 3, pp. 298-361, 1931.

the location of its maximum in the case of each profile. In every instance it will be noted that this maximum occurs somewhat down the dip from the crest line of the corresponding topographic ridge.

Fig. 3 represents diagrammatically the approximate relations between the crest line of a basalt ridge and of the maximum electrical resistivity of the same stratum when eroded in

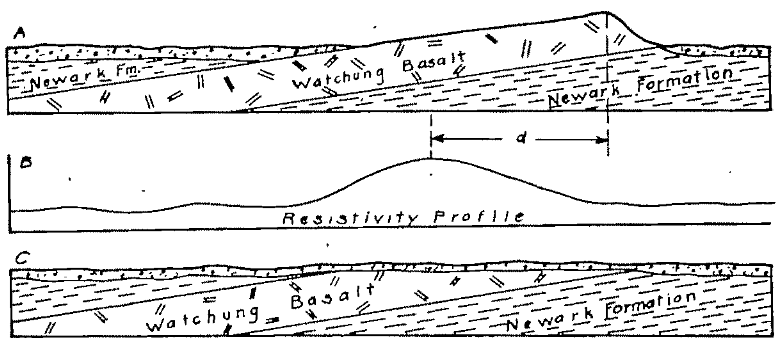

Fig. 3. Diagrams showing the approximate relations between the position of the topographic crest line of a trap ridge and of the resistivity maximum of the same rock in a gap. *d* represents the displacement down the dip.

a gap. The maximum of resistivity would occur somewhat down the dip from the uneroded topographic crest line.

Conclusion.

In all of these profiles the occurrence of the maxima were approximately as would be expected on the hypothesis that the trap were present under the glacial drift in each case, and seems, therefore, to indicate the presence of the trap. The decline in the magnitude of the maxima in the succeeding gaps is apparently due to a progressively increasing depth of burial of the trap in each instance. This accords with Johnson's interpretation that the gaps were carved by the Hudson River when flowing southwestward across the trap sheets, so as to give gaps progressively deeper downstream. The apparatus used was not of the kind to provide reliable depth determinations.

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SCIENTIFIC INTELLIGENCE.

Physics.

Optische Messungen; by Dr. Fritz Löwe. Pp. 205; 58 figs., 4 tables. Dresden, 1933. (Theodor Steinkopf, 9 RM. 10 RM. bound). This booklet, *Band VI* in the *Technische Fortschrittberichte*, appears admirably to fulfill its purpose of explaining, in brief and concise form, optical instruments and measurements which are useful in technical and industrial work. It should prove valuable especially to chemists and physicians who have not had the time or the opportunity to follow the latest developments in optical technique. A. T. WATERMAN.

Resonance Radiation and Excited Atoms; by Allan C. G. Mitchell and Mark W. Zemansky. Pp. xvi, 338; 84 figs. Cambridge: at The University Press. New York, 1934 (The Macmillan Co. $5.00). The study of resonance radiation, discovered in 1904 by R. W. Wood, has yielded important information about the interaction of light and matter. From the quantitative relations existing between the various frequencies in their spectra, we have with aid of modern quantum theories learned much about the structure and dynamical behavior of individual atoms and molecules. Resonance spectra are a particularly simple and basic illustration of the procedure in this branch of modern atomic physics. This book gives the first comprehensive account of the whole subject of resonance radiation of atoms, a field in which both of the authors have made numerous original contributions. The main topics treated are physical and chemical effects connected with resonance radiation, absorption lines and measurements of the lifetime of the resonance state, collision processes involving excited atoms, and the polarization of resonance radiation. Apparently all the work of any importance coming under these headings is given at least a cursory discussion. Long bibliographies at the end of each chapter are a valuable feature.

There is no attempt to avoid the use of mathematics in this book, but extended mathematical proofs are gathered into an appendix. Anyone interested in atomic physics will find here a clearly-written, unified account of both the experiments and the theories in this interesting subdivision of modern spectroscopy. A similar work in the closely related field of resonance and fluorescence spectra of molecules would be of much value. W. W. WATSON.

Geology and Mineralogy.

Untersuchungen zum Bau des Kaledonischen Gebirges in Ostgrönland; by Curt Teichert. Meddel. om. Grönland, Bd. **95**, No. 1, pp. 119, 2 pls., 41 text figs., 1933.—The author of this paper

joined the Lauge Koch expedition to East Greenland in the summer of 1931 and returned at the close of the field season of 1932. He studied mainly the structural relations of the late Proterozoic and early Paleozoic series between latitudes 76° and 73° N., and their relation to the late Devonian. The greater part of the interesting memoir is taken up with a detailed description of seventeen closely spaced east-west traverses. To the west, at the inner ends of the fiords and the ice margin, the basement rocks consist of pre-Algonkian gneiss. To the east of the gneiss there is a thick sedimentary sequence named Petermann series, the age of which is unknown, but which is thought to be equivalent to the upper part of the Algonkian. Farther east is more gneiss, followed by a very thick sedimentary succession, the Eleonore Bay formation of Koch, from 12,500 to 13,150+ feet thick. Resting conformably upon this is a similar sedimentary sequence of Cambrian, Ozarkian, Lower Ordovician and a little of Middle Ordovician strata. Teichert thinks the break above the Eleonore Bay formation is of short duration, but the Middle Ordovician is followed by a very long break, since the next series is late Devonian in age and of continental origin. Between the Algonkian, with beds of *Cryptozoon* (*Collenia*), and the Cambrian strata lies a widespread fresh-water sandstone with several tillite beds (for its distribution, see his page 104), and even though there is no transition into the marine Lower Cambrian, Teichert refers the tillite series to the Paleozoic. Farther east, unfolded Devonian lies upon granite.

At the north, the Proterozoic-Paleozoic strata are not folded but lie in broad undulations; to the south they become more and more strongly folded and thrust westward over the gneiss. The Devonian is not folded but is somewhat undulatory and more or less faulted. Therefore the time of the orogeny cannot be fixed in detail, other than that it was after Middle Ordovician and before late Devonian time, the general assumption being that it was of Caledonian age. No mountain making occurred between late Proterozoic and early Cambrian times.

The memoir is a valuable addition to general geology, treating, as it does, of a region that is difficult to master under the very trying conditions of arctic climate. C. S.

Merostomata from the Downtonian Sandstone of Ringerike, Norway; by LEIF STÖRMER. Skrift. Norsk. Vidensk. Akad. Oslo, I. Math.-Naturv. Klasse, 1933, No. 10, 125 pp., 12 pls., 39 text figs., 1934.—The author has devoted a great deal of time, both at home and in the United States, to the working out of the morphology and the relationships of the ten species of Merostomata found in the lowest strata of the Lower Devonian in the Oslo district. These fossils occur about 14 feet beneath the fish beds, which are 20 inches thick, and which have the wonderfully interesting Anaspida described in great detail by the late Professor Kiaer

(1924). Of eurypterids there are eight species, six of which are new, but of only one, the small *Hughmilleria norvegica,* is an abundance of material known. *Mixopterus kiaeri,* about 2 feet long, is by all means the most interesting of the forms, and has the best preserved material, making possible its restoration from both dorsal and ventral sides. Material is also present of *Pterygotus* (2 species), *Stylonurus* (3), the synziphosuran *Bunodes,* and the limulid *Kiaeria,* n. gen.

Following the introductory matter, pages 11-79 are devoted to the morphology of the Eurypterida and their relation to the Xiphosura, Chelicerata, Pedipalpi, and Scorpionida. The taxonomic descriptions occupy pages 80-121, and the bibliography cites 103 titles.

The author gives a long discussion (pp. 43-52) of the "median appendages" in the various eurypterids. These appendages, which are of two general types, are interpreted as sex organs, as first argued by Gaskell (1908). Either four or five pairs of abdominal gill chambers are present, and these are closed by gill plates. "Hardly any doubt remains as to the limb nature of the abdominal plates in Xiphosura and Eurypterida." These small gill plates, the author also argues, are used for swimming, in addition to the large last pair of prosomal limbs. The nineteen genera of Eurypterida, here arranged in four families (Pterygotidae, Stylonuridae, Carcinosomidae (new), and Eurypteridae), all had their origin at least as early as the Middle Ordovician, indicating that "the branching of the eurypterid stock took place in very early times." The author is not able to present a genealogical tree.

All in all, this work ranks among the classics treating of the Eurypterida. C. D.

The Geology of Capetown and Adjoining Country. An Explanation of Sheet No. 247 (Capetown); by S. H. HAUGHTON. With a chapter on Underground Water Resources by H. F. Frommurze. (With colored map 22 × 33 inches). Union of South Africa Geological Survey. Pretoria, 1933.—The text briefly sketches the topographic features and discusses the stratigraphy and structure of the region (nearly 1,400 square miles) centering about Capetown. A short chapter is devoted to the igneous rocks, another to economic geology, and a final one to groundwater.

The region is formed chiefly of two major groups of rock, (1) the Cape Series (Devonian) of shales and sandstones somewhat less than 5,000 feet thick, and (2) a pre-Cape series of metamorphosed sedimentary rocks and igneous intrusives. These are separated by a profound unconformity. The lowland includes an extensive area of late Tertiary and Recent sands. At Table Mountain the Cape Series includes a boulder bed to which a glacial origin is ascribed. The excellent map is on a scale of 2.35 miles per inch. C. O. DUNBAR.

Man and the Vertebrates; by ALFRED SHERWOOD ROMER. Pp. vii, 427. 278 figs. Chicago, 1933 (University of Chicago Press, $3.00).—Written in an interesting, non-technical style, this text is one of the best of the recent books on the evolution of the vertebrates. From the standpoint of comparative anatomy, paleontology, and embryology, it gives a complete and comprehensive survey of their organic evolution. There is a good general account of the anatomy, origin, and development of man. As Romer says, "We have not been 'built to order,' but are the end-result of an enormously long series of evolutionary changes. The human body bears its history indelibly stamped upon it." The author has expressed this very clearly and succinctly. The book is highly recommended for college students reading in the biological sciences or for the general reader who wishes a well-written account of his human origin. N. E. WRIGHT.

The Geology of the Country around Reigate and Dorking; by H. G. DINES and F. H. EDMUNDS. Notes by H. DEWEY and C. J. STUBBLEFIELD; palaeontology by C. P. CHATWIN. Pp. vii, 194; 5 pls., 15 figs. (H. M. Stationery Office 4s. net).—This text is accompanied by a colored geological map (sheet 286, 1 inch to 1 statute mile, price 2s, postage extra). The formations present in this area extend from the Wealden beds of the Lower Cretaceous through the Chalk of the Upper Cretaceous to the Bracklesham Beds of the Tertiary. The Pliocene, Pleistocene and recent surface deposits are also included. Of interest on the economic side are the deposits of Fuller's Earth, also the water supply, shown by the many new well sections.

Illinois Geological Survey, M. M. LEIGHTON, Chief.—The following publications have been recently issued: Report of Investigations. No. 28, Mineral Industry in 1932 by W. H. VOSKNIL and ALMA R. SWEENEY. Pp. 65 with map (p. 66).

No. 29. Electric Condenser Process for demulsifying Oil; by R. J. PIERSOL. Pp. 38, with 10 figures and bibliography.

No. 30. Oil and Gas Possibilities of parts of Jersey, Greene and Madison Counties, by D. M. CALLINGWOOD; also Well Records by G. E. EKBLAW and L. E. WORKMAN. Pp. 91, 3 pls., 4 figs., 4 tables.

No. 31. Briquetting Illinois Coals, without a Binder, by compression and by impact; by R. J. PIERSOL. Pp. 76, 14 figs., 9 tables.

State Publications, with those of the U. S. Bureau of Mines, and U. S. Geological Survey. Pp. 83; Index Map, p. 38.

New Mexico School of Mines, State Bureau of Mines and Mineral Resources, E. H. WELLS, Director.—Bulletin 7. Metal Resources and Economic Features; by S. S. LASKY and T. P. WOOTTON.—An interesting summary of the mineral products of a

state particularly rich in gold, zinc, copper, also silver, lead and other metals. The preliminary summary is followed by statements from the separate counties with two large maps at the end.

Microscopic Determination of the Non-opaque Minerals. (Bulletin U. S. G. S. No. 848, price 20 cents).—This is a new edition of Bulletin 679 which appeared in 1921, and was the first reference work to give a systematic compilation of the optical properties of non-opaque minerals. This work on the microscopic determination of indices of refraction made possible the wide application of the most accurate method yet devised for their identification. For this reason the earlier edition has been widely used throughout the world.

The new edition of 254 pages has been completely rewritten and the tables brought up to date by the introduction of about 500 new entries and 100 changes in old entries. Some 250 new mineral species, not given in the old edition, are included, and tables have been added in which the data on the important mineral groups have been assembled. The new edition thus supersedes the earlier one and will be a necessary reference work for all those who have occasion to identify minerals.

Le Gite d'Uranium de Shinkolobwe-Kasolo (Katanga); by J. THOREAU and R. DU TRIEU DE TERDONCK, Mém. l'Inst. Col. belge (Sect. Sci. nat. et méd.). Vol. I, No. 8; 47 pls., 46 pp. Brussels, 1933.—The rich and extraordinarily varied mineralogy of the Katanga uranium deposit has been already abundantly described but practically nothing on the geological relations of the ores has been published. The authors of this paper have had years of experience in the study of these deposits which finds expression here. Professor Thoreau teaches economic geology at Louvain; Du Trieu de Terdonck is chief geologist of the Union Miniére du Haut-Katanga. The authors present an outline of the structural relations of the whole region and discuss in detail the structures revealed in the mine workings. An extensive study was made of the paragenesis of the deposit, data being gathered from field observations and from a careful study of thin and polished sections.

The Shinkolobwe ores occur in the calcareous and dolomitic "série des Mines," at the west end of the tectonic area which contains the Katanga copper ores. Numerous longitudinal faults, including a very considerable one separating the "série des Mines" from the overlying Kundelungu schists, complicate the local geology. Maps and sections illustrate the relations.

The primary pitchblende veins tend to be grouped where favorable horizons are cut by fracture zones. Unlike that of the Great Bear Lake region, the pitchblende is coarsely crystalline, resembling the uraninite of pegmatites. The Shinkolobwe deposits are, however, hydrothermal in origin, probably of the same metallo-

genetic epoch as the copper ores to the east. Under conditions of the zone of oxidation, black pitchblende gives rise to brilliantly colored alteration products encircling the primary mineral as discrete bands. The initial secondary process was replacement of pitchblende by hydroxides of uranium and hydrated lead uranates. Surrounding and attacking the "orange zone" so produced is a "green zone" of uranium phosphates. Finally, through the country rock, abundant torbernite has been disseminated. From many thin and polished sections, excellent microphotographs are reproduced to support the contentions of the authors concerning the detailed mineral sequence. It is pointed out that a common result of the break-down of the primary mineral is the formation of two new minerals, one without lead, the other a lead compound (example: becquerelite and curite). The conclusion is reached that the Pb/U ratio of the secondary minerals of the whole deposit, including both veins and disseminated mineralization, is the same as that of the primary uraninite. Though other primary sulphides are present, especially linneite, chalcopyrite and molybdenite, galena is lacking.

No clue is offered to the source of the phosphorus in the extensive late phosphate mineralization. The only primary phosphate is monazite, which is resistant to alteration.

Of special interest to those interested in the microscopic study of ore minerals is a section on properties of many uranium minerals in polished section; furthermore the illustrations show a wealth of variety of ore textures.

C. PALACHE AND W. F. JENKS.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Studien über die Cycadeen des Mesozoikums nebst Erörterungen über die Spaltöffnungsapparate der Bennettitales; by RUDOLF FLORIN. Kgl. Svensk. Vet.-Ak. Handl., 3rd Ser., B. 12, No. 5. Pp. 134; with 16 pls., 40 text figs. (Stockholm, 1933).—In this comparative study of stomatal structure in fossil and existent cycadeous vegetation Florin comes to his subject extremely well prepared, having but recently brought out a most elaborate treatise on the phylogeny of Conifers and Cordaites (Untersuchungen zur Stammesgeschichte der Coniferales und Cordaitales (Kgl. Sv. Vet.-Ak. Handl., B. 10. Pp. 588, and many text figs. Stockholm, 1931). Moreover there has meanwhile appeared the very significant account of the Fossil Floras of Scoresby Sound, East Greenland, by T. M. Harris (Meddelelser om Grönland, B. 85, Nos. 3 and 5. Copenhagen, 1931, 1932).

The methods used in this newer work, marking a decided increase in accuracy over all previous studies of the carbonized imprints, are those first developed by A. G. Nathorst, some years ago, and since widely used by H. H. Thomas, Kraeusel, and other European paleobotanists, although not as yet seriously applied to the investigation of any of the American fossil floras. The subject

as a whole takes the form of a most important contribution to plant anatomy and classification.

Almost throughout the gymnosperms, epidermal features and stomatal structure are so persistent in their several variations and types as to reach true diagnostic values. Florin, after searching and elaborately illustrated examinations of stomatal structure and development, finds that existent cycadeous forms are of uniformly "haplocheilous" (or simple-lipped) deep set stomatal type; while so far as can be learned from fact or inference the cycadeoids are "syndetocheilous" (composite lipped), with the stomata mostly shallow and at right angles to the venation.

Syndetocheil stoma in fact occur so widely and persistently in both heavy columnar and small stemmed freely branched cycadeoids as to afford not only a point of separation, but to become a veritable "baton sinister" of extinction. That stomatal structure and distribution may often be relied on in classifying the varied cycadophytan vegetation of the Mesozoic thus already seems certain. Nevertheless, I am much inclined to protest the validity of Dr. Florin's view that a classification of the amazing group cycadophyta, which I essayed some fifteen years ago, has become "werthlos"! The object then sought was merely to reach a handy, or suggestive, provisional grouping. As was said then such a classification could only have value as discovery progressed "if it had both flexibility and impermanence." For surely all fair attempts at fossil classification must have some initial value; and now, unless the point is much misjudged, interpolation of the findings of Florin and Harris, in that earlier alignment, would clear it of some of its initial artificiality. Uncertainties ever and unavoidably beset all orderly groupings of ancient plants..

G. R. WIELAND.

The Design and Use of Instruments and Accurate Mechanism; by T. N. WHITEHEAD. Pp. xii, 283; 85 figs. New York, 1934 (The Macmillan Co., $3.50).—This book is intended primarily for the designers and users of instruments. The text treats largely of the instruments for linear measure but the principles set forth apply with equal force to instruments of other types and to mechanism in general.

The work is divided into two major parts. Part I discusses the theory of errors and includes separate chapters on the various classes of errors. This part also includes chapters on Probability as Applied to Errors and another chapter on the human equation. The discussion is made more graphic by the use of specific examples. Part II treats of the design of instruments. This section discusses the design of an instrument from the standpoint of precision and accuracy and contains a chapter on the planning of an instrument.

The book is written in an interesting style and is well illustrated with line-drawings and half tones. FREDERIC W. KEATOR.

Obituary.

Francis Arthur Bather, F.R.S.

1863-1934.

F. A. Bather, whose death on March 20 was recorded in an earlier number of this Journal, graduated from New College, Oxford, in 1886, with the M. A. degree, taking first-class honors in natural science. The following year he became assistant in the Department of Geology in the British Museum (Natural History), where he had charge of fossil echinoderms, and here he remained until his retirement in 1928. In 1902 he was made deputy keeper, and in 1924 keeper, of the department. Much honored at home and abroad, he was President of Section C of the British Association in 1920, and for two years (1927, 1928) president of the Geological Society of London; and his three presidential addresses, "Fossils and life," "Biological classification: present and future," and "The fossil and its environment" are notable contributions to the philosophy of Paleozoology.

Bather began to publish in 1886, first on geological subjects and then on cephalopods, but ever since 1889 his main paleontologic interests have been with the echinoderms, and more specifically with the crinoids. He also made a special study of the "technics" of museum and laboratory, of bibliographic methods, and of rules of nomenclature, and he did valuable editorial work, first with the excellent but short-lived *Natural Science*, and later with the effective *Museums Journal*. His hundreds of brief notes and reviews, his longer papers, and particularly his memoirs and monographs evince a deeply analytical and philosophical mind, a lucid style, a strong sense of law and order, and a habit of forthright speech. As an example of his critical analysis may be cited his review of the two-volume Wachsmuth and Springer monograph on the Crinoidea Camerata (1897), which occupies 64 pages.

It can truthfully be said that Bather advanced general knowledge of the morphology and classification of the stalked Echinodermata more than any other paleontologist of his time. Of greatest help to the greatest number are his annual "Record of, and index to, the literature of Echinoderma," which began to appear in 1894 in the *Zoological Record*; and his valuable volume, "The Echinoderma" in Lankester's "Treatise on zoology" (1900). His first great work on crinoids is entitled "The Crinoidea [Inadunata] of Gotland" (200 pages, 1893), but the work that Bather considered his masterpiece is "Caradocian Cystidea from Girvan" (170 pages, 1913). Another monumental work is "Studies in Edrioasteroidea" (120 pages, 1899-1915).

Charles Schuchert.

OBITUARY.

DR. JAMES Y. SIMPSON, Professor of Natural Science in the University of Edinburgh, died at his home on the 21st of May in the 60th year of his age. He had just returned from a lecture tour in America, when he was stricken down. Doctor Simpson was Terry Lecturer at Yale in 1929, speaking along the line of his chief interest, that of the reconciliation of Science and Religious Faith. Several important volumes, have come from his hand; "The Spiritual Interpretation of Nature," 1912; "Man and the Attainment of Immortality," 1922; and "Landmarks in the Struggle between Science and Religion," 1925. He was also interested in Russian affairs and in 1919 was a British delegate to the Versailles Peace Conference. He was a man of charming personality and endeared himself greatly to all who had the privilege of knowing him. RICHARD S. LULL.

DR. ROBERT CHODAT, since 1889 professor of botany at the University of Geneva and director of the Botanical Institute, died recently at the age of sixty-nine.

DR. EDWARD WILLIAM NELSON, chief of the Federal Bureau of Biology, died on May 19 at the age of seventy-nine.

DR. HENRY T. KOENIG, the Denver chemist, well known for his valuable work on radium, died on June 17 at the age of forty-two.

DR. ROBERT HENRY WOLCOTT, professor of zoology at the University of Nebraska, died on January 23, at the age of sixty-five.

DR. CHARLES HENRY GORDON, State Geologist of Tennessee, 1910-1914, professor of geology at the University of Tennessee, 1907-1931, died on June 12 at the age of seventy-seven.

DR. STUART RAEBURN KIRK, assistant professor of geology in the University of Manitoba since 1927, and field-officer of the Geological Survey of Canada during that time, died at Winnipeg, on May 15. He was graduated from St. Andrew's University of Scotland in 1922, and studied at Yale from 1925 to 1927.

PUBLICATIONS RECENTLY RECEIVED

Embryology and Genetics; Thomas Hunt Morgan. New York, 1934. (Columbia University Press, $3.00.)

Soil Analysis by C. H. Wright. London, 1934. (Thomas Murby & Co. 12/6d net.)

Dip and Strike Problems. Mathematically surveyed. Kenneth W. Earle. London, 1934. (Thomas Murby & Co., 12/6.)

The Dinosaurs by W. E. Swinton. London, 1934. (Thomas Murby & Co., 15/net.)

The Phenomenon of Superconductivity, edited by E. F. Burton. Toronto, 1934. (The University of Toronto Press, $2.50.)

The Carnegie Foundation for the Advancement of Teaching. Annual Review of Legal Education; by Alfred Z. Reed. New York, 1934, 522 Fifth Ave. (No charge.)

Carnegie Institution of Washington. Supplementary Publications No. 7. Racing Capacity in the Thoroughbred Horse. Part I—The Measure of Racing Capacity. Part II—The Inheritance of Racing Capacity; by Dr. Harry H. Laughlin. Pp. 26; 6 figs.

Geological Society of America. Memoir 1. Stratigraphy of Western Newfoundland; by Charles Schuchert and Carl O. Dunbar.

Exploring the Upper Atmosphere; by Dorothy Fisk. New York, 1934. (Oxford University Press, $1.75.)

Sky Determines, An Interpretation of the Southwest; by Ross Calvin. New York, 1934. (The Macmillan Co., $2.50.)

American Inventors; by C. J. Hlander. New York, 1934. (The Macmillan Co., $2.00.)

Actualités Scientifiques et Industrielles. 89. Conductibilité Electrique et Thermique des Métaux par Léon Brillouin. 90. Adsorption, Electro-Reduction and Overpotential displayed at the Droping Mercury Cathode by J. Heyrovsky. 91. Phénomènes Photoélectrochimiques Action de la Lumière sur le Potentiel Métal-Solution par René Audubert. 92. Les Colloides et la Couche de Passage par A. Gillet et N. Andrault de Langeron. 93. Sur le Potentiel Métal/Solution dans les Dissolvants autres que L'Eau par Paul Dutoit. 94. La Laccase et le Laccol par Georges Brooks. 104. Les Phénomènes Périodiques de la Chimie. I. Les Périodicités de Structure par Suzanne Veil. 105. L'Inflammation et la Combustion Explosive en Milieu Gazeux. 2e Partie; Les Hydrocarbures par M. Prettre. 108. Equilibre de Membrane par N. Marinesco. 130. L'Effet Electro-Thermique Homogène par Carl Benedicks. 131. Die Theorie der Thermoelektrischen Effekte von Lothar Nordheim. 132. La Notion de Corpuscules et D'Atomes par Paul Langevin. 111. V. Mécanique Quantique et Chimie par G. Allard.

Carnegie Institution of Washington. News Service Bulletin. Vol. III, No. 16. The Desert and Its Life.

Smithsonian Miscellaneous Collections, Vol. 90. World Weather Records; arranged by H. Helm Clayton.

AMERICAN JOURNAL OF SCIENCE

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GEOLOGICAL RECONNAISSANCE OF CENTRAL SONORA.

ROBERT E. KING.

The present paper is the result of reconnaissance geological work by the writer in the central part of the State of Sonora,

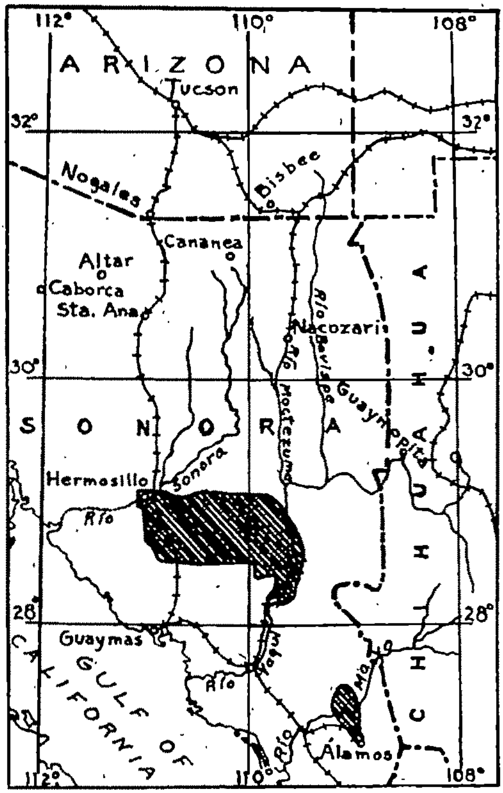

Fig. 1. Index map of Sonora, to show areas (shaded) described in the text.

Mexico, in 1931 and 1932, which had as its primary object the collection of data concerning the Paleozoic strata first noted in that region by Dumble[1] (Fig. 1). Dumble's observations

[1] Dumble, E. T.: Notes on the Geology of Sonora, Mexico. Trans. Am. Inst. Min. Eng., 29, pp. 122-152, 1900.

were very sketchy, no map accompanied his report, and most of his localities can be found only on the most detailed state maps. Nothing further was written concerning the Paleozoic rocks of this region until the work of Teodoro Flores[2] appeared. As will be seen below, Flores assigned the Paleozoic strata of the vicinity to the Jurassic.

My field work was made possible by the generous financial assistance of Professor Charles Schuchert. I constructed a sketch map from pace traverses, doing all field work afoot or on horseback. The extent of the several areas of Paleozoic rocks was determined, and I attempted to establish the structural relations of the region. The present preliminary paper is being published in advance of further work in the same region and to the east of it.

The fusulinids collected were examined by Professor C. O. Dunbar, and his identifications are cited in the following text.

Area studied—The section of Sonora studied during the course of this work lies between 28°15′ and 29° N. Lat., and extends from the Río Yaqui on the east to Hermosillo on the west. My own field observations are supplemented in the western part of the area by maps and data of Flores, which I have taken the liberty to interpret in the light of my own findings (Fig. 2).

GEOMORPHOLOGY.

The area studied lies in three large drainage basins—those of the Ríos Sonora and Yaqui on the west and east and of the Arroyo de Mátape in the center (Fig. 2). The western part of the area, lying west of the 110th meridian, has a pediment-inselgebirge topography like that described by Bryan in the Pápago country.[3] There are three principal mountain massifs in this section. The western is that of La Colorada, a north-south chain of fault-block mountains separated from one another by pediments. East of this across the Mátape valley is the high east-west trending Sierra de Tecoripa, separated by a valley from the Sierra de Cobachi, which terminates to the north in the high Permian limestone mountain of Cerro Cobachi (Fig. 2). North-northeast of this is a broad round-topped granite mountain, the Sierra de Mazatán. Dividing the

[2] Reconocimientos Geológicos en la Región Central del Estado de Sonora. Inst. Geol. de México, Bol. no. 49. Mexico, 1929.

[3] Kirk Bryan: Erosion and Sedimentation in the Papago Country, Arizona. U. S. Geol. Sur. Bull. 730, 1922.

different massifs from one another, and separating them from the high range east of the 110th meridian, is an extensive pediment plain eroded from granite thinly mantled with lavas.

In the eastern part of the area studied there is a north-south chain of high mountains, elongate about N. 25° W., and averaging 20 kilometers in width, lying along the west side of the Río Yaqui. This range is formed of Triassic quartzites intruded by igneous rock, and is believed to be an overthrust nappe. It terminates to the south of San Javier, and is succeeded in that direction by irregular metamorphic and igneous ranges separated from one another by narrow granite pediments.

Between the San Javier range on the west and the next parallel range to the east lies the north-northwest-trending intermontane valley which extends from La Dura on the south to beyond Rebeico on the north. South of Soyopa this valley is followed by the Río Yaqui. The width of the valley averages 10 kilometers. It is traversed by low north-south hogback lava ridges, between which are low-lying strips underlain by agglomerate.

South of La Dura the Yaqui enters the region, above mentioned, of irregular ranges of metamorphic and igneous rock intruded by granite. Throughout its course the river loops back and forth from resistant rock into soft agglomerate, as if it had entrenched itself from a former period of meandering.

Between La Dura and Soyopa the intermontane valley of the Yaqui is bordered on the east by a high range of quartzite and plutonic rock, a western ridge of the main Western Sierra Madre. The Yaqui cross-cuts this range north of Soyopa, and the continuation of the range toward the north-northwest of the Yaqui canyon is known as the Sierra de Soyopa. Through the area studied, the Río Yaqui makes an acute angle with the main structural trend of N. 25° W., its course being nearly due south. However, to the north, at Lat. 29°15′ N., the river makes a right-angle bend to the east directly crossing the high ranges of the sierra. In the same strike valley which is occupied by the Yaqui below the great bend, the Río Moctezuma flows south from Nacozari (Fig. 1).

Alluvial fans are developed only on the flanks of fault-block mountains. The only large fans in the area examined border the Sierra de Cobachi, especially along the eastern fault scarp of that range. Where normal erosion processes have continued for a long period without interruption by uplift, broad

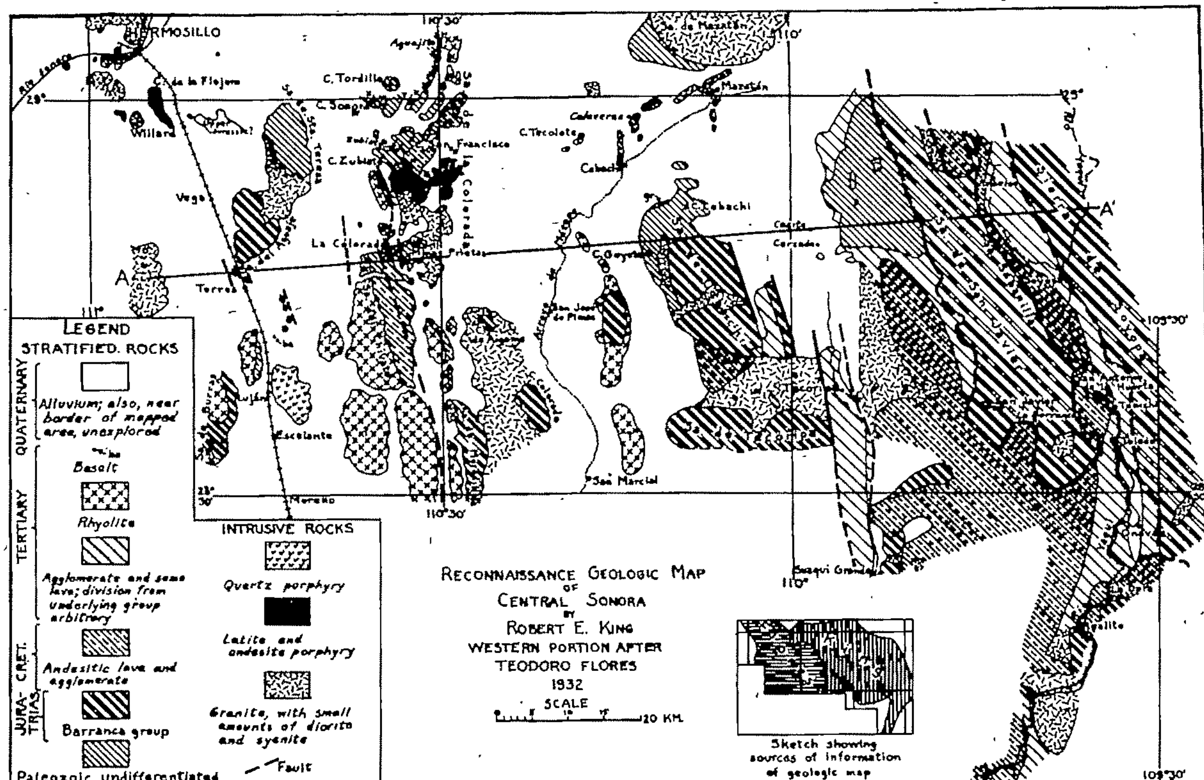

Fig. 2. Reconnaissance geologic map of central Sonora.

pediment surfaces are formed, more or less sheeted over by waste.

Several different levels of pediments are to be observed. A careful comparison of the levels would make possible their correlation from place to place, and the working out of the erosional history of the Quaternary, as was done by Kirk Bryan in the Pápago country.

The region is arid, though covered in most places with heavy brush, which is nearly impenetrable in most of the mountainous sections. The part of the area west of the Sierra de San Javier is covered with more or less grass, greasewood, mezquite, ironwood, sahuaro, pitahaya, cholla, palo verde, and other thorny trees and cacti such as are characteristic of southern Arizona. In the high mountains in the eastern part of the region there are tall trees, many of them thornless, and grass grows luxuriantly.

STRATIGRAPHY.

The following table represents the succession of sedimentary and volcanic rocks in the region:

Quaternary.	Alluvium, generally thinly mantling the pediments, rarely forming great fans.	
Tertiary.	Basalt, in western part of region. Agglomerate interbedded with thin flows of andesite and rhyolite; in the western part of the region capped by a thick flow of rhyolite. Total thickness over 1000 m.	
Cretaceous?	Lista Blanca formation of Dumble?	Dense dark-grey andesitic lava flows separated from one another by indurated agglomerate. Thickness over 1000 m.
Upper Jurassic?	Limestones near Willard station and Zubiate, assigned by Flores to Upper Jurassic on the basis of crinoid stems. May be late Paleozoic in age.	
Liassic and Upper Triassic.	Barranca group.	Two members of massive sandstone divided by a thin-bedded sandstone and shale member, containing coal and graphite. Thickness about 1500 m.
Permian.	Equivalent of upper Naco limestone of S. Arizona.	Crinoidal and fusulinid limestone. Thickness about 600 m.
Ordovician.	Dark-grey to black limestone, commonly cherty, sandstone, and one layer about 50 m. thick of massive white coralline limestone (late Ordovician).	

Lower Paleozoic.—Lower Paleozoic strata crop out in two areas. The eastern area lies on the east side of the highway between the towns of Mazatán and Tecoripa. The western lies about 12 kilometers to the west in the northern part of the Sierra de Cobachi (Fig. 2). In both areas dips are high and irregular, the hills formed by sediments being separated by strips of igneous rock, and the whole country being covered heavily by brush, making it difficult to work out the actual sequence. Dumble described northeast of La Casita a thick series of quartzite and marble of "Cambrian" age (but without fossils), succeeded unconformably by fossiliferous limestone of the "Silurian." I was unable to find any section as simply arranged as this.

The most persistent horizon in the lower Paleozoic is a very massive layer of blue-grey, white-weathering limestone, containing stringers of black chert in part. It is everywhere much pitted by solution. The thickness of this layer is about 50 meters. In the eastern area it forms low hills in the southern and southwestern part, northeast of the house known as La Casita, and in the western area it forms the Cerro Goyete, southwest of Cerro Cobachi. The limestone contains abundant corals of the genus *Palaeophyllum* and rare *Calapoecia, Streptelasma* and *Heliolites*. This is the "Silurian" fauna reported by Dumble, but the fossils indicate late Ordovician (Richmondian) age.[4]

Adjoining this big limestone in the southwestern part of the eastern area of lower Paleozoic, and either above or below, though probably below it, there is a confusing complex of dark-grey to black limestone containing brown and black chert layers and concretions and siliceous shale, interbedded with thin layers of quartzite and clayey buff-colored limestone. In places layers of angular chert-pebble conglomerate were seen, and at one locality there is a platy dark limestone which is brecciated in broad flat pebbles. The black limestone looks very much like that in the Marathon region of west Texas which there contains such a prolific fauna of graptolites, but none of those fossils could be found here. The dips are

[4] Schuchert originally reported the fossils to be *Cyathophyllum* and *Heliolites*, and they were so cited by Dumble. In 1909 he re-examined them, and in his notes wrote, "These fossils are now before me and I see that they are of the southwestern Richmond. The most abundant coral is *Palaeophyllum* but not *P. thomii* (Hall). Next a *Calapoecia* near *C. canadensis* and a small *Streptelasma*." The writer collected additional specimens of these species.

extremely irregular in angle and direction, but the strike has a general east-west trend. The sequence of the beds could not be worked out in this division, nor were any fossils found. These strata must be those which Dumble assigned to the "Cambrian," but their lithologic resemblance is greater to the Ordovician of Texas.

The western area of lower Paleozoic strata is about 10 kilometers long, extending as a range of low-lying rugged hills elongate from north to south. Some Pennsylvanian or Permian strata are probably included in this complex. The dips and strikes here, as in the Casita area, are very irregular, and the interpretation of the structure and stratigraphy is difficult. In many places it is impossible even to determine the dip, because the strata are completely broken down along numerous joint planes, leaving only angular fragments on the surface. Aside from the fossiliferous limestone of Cerro Goyete and a limestone containing crinoids and bryozoans 3 kilometers north of Cerro Goyete, the area consists of brown and red sandstone and quartzite and cherty and siliceous limestone.

Permian.—Limestones of this age are much more widespread than lower Paleozoic strata. They seem to be a southern extension of the upper or Permian portion of the Naco limestone of southeastern Arizona. Generally, the limestone is almost made up of crinoid stems and fusulinids. Great reefs of massive limestone similar to those of West Texas form high mountains such as Cerro Cobachi and Cerro San Francisco north of Zubiate (Fig. 2). In intervening areas the limestone is darker in color, thinner bedded, and made up of small waterworn fragments of crinoid stems, and rarely fusulinids.

Brachiopods were found in only one place, south of the belt of massive coralline limestone lying northeast of La Casita. These were poorly preserved, but a *Linoproductus* was distinguished. North of there, in the same Paleozoic area, the hills east of Las Arrastras, composed of east-dipping light-grey massive limestone, contain *Parafusulina* of about the same age as that in the limestone of Cerro Cobachi.

Cerro Cobachi is a high hogback dipping to the south, formed of bluish-grey limestone, probably 500 meters thick. The limestone appears to be a reef mass, and to the west it breaks up into thinner limestone beds. In this region it contains many crinoid columnals and an abundance of fusulinids of two species. One is a *Paleofusulina* very near to, if not

identical with, *P. gümbeli* of the Leonard horizon of west Texas. The other form is larger and not yet identified. The limestone appears to thin considerably east and west from Cerro Cobachi, and is either cut off by intrusive granite or faulted off. The limestone dips toward the older Paleozoic on the south, and is probably downfaulted against it.[5]

West of the Arroyo de Mátape, Paleozoic sediments appear again in the northern part of the Sierra de la Colorada. They were assigned by Flores almost entirely to the Oxfordian division of the Upper Jurassic on the basis of stems of *Apiocrinus* in the Cerro de Sonora, and of *Millericrinus* in the hills east of Willard station, identified by Burckhardt. I did not visit these exact localities, but in the Cerro de San Francisco a few kilometers east of the Cerro de Sonora I found abundant fusulinids in crinoidal limestone, and in the Cerro de la Flojera north of Willard I found a few fusulinids in granular crinoidal limestone. These finds throw grave doubt on the correlation of crinoidal limestones in the same vicinity with the Jurassic on the basis of such doubtful fossils as crinoid stems, even by so eminent a paleontologist as Dr. Burckhardt.

In the La Colorada mining district there are quartzite and limestone which are much altered, shattered, and intruded. They are probably of Paleozoic age, though no fossils were found. The Cerro San Francisco, northeast of Zubiate, is made up of hundreds of meters of massive light-grey limestone, forming a reef nucleus which grades laterally into thin-bedded cherty, granular, crinoidal limestone bearing fusulinids. Cerro Zubiate, southwest of Zubiate, is likewise formed of a massive reef limestone. A number of other hills in the same vicinity

[5] Dumble stated that the eastern face of Cerro Cobachi is formed by Cambrian rocks, consisting of "banded quartzites, marbles, etc., standing at a very high angle with the Cretaceous beds, having a comparatively gentle dip toward the west, resting upon their strongly-eroded edges. In the foothills southeast of this place the Silurian rocks succeed the Cambrian, but the contact was not observed. . ." The Cretaceous limestones containing supposed silicified hippuritids "are unconformable with all underlying rocks. . . Further south, on the western face of the main mountain, the limestones rest upon the upturned edges of a series of marbles and quartzites, which are provisionally referred to the Cambrian. Along the southern and eastern faces little was seen except the Cretaceous beds, which, in some places, are worn into great caves."

In my reconnaissance study of the region I did not find the unconformity mentioned by Dumble in the above quotations. However, I proved by fossil evidence that the supposed Cretaceous is really Permian, and if, as Dumble states, there is a profound angular unconformity below what he called "Cretaceous," the unconformity really represents the break below the Permian—an unconformity which is widespread throughout Arizona, New Mexico, and west Texas.

are evidently formed of Permian limestone. West of the Southern Pacific Railroad and south of Hermosillo there are several ranges of seemingly Permian limestone (though regarded by Flores as Upper Jurassic). The principal one is the Sierra de Doña Marta, along the south side of the Río Sonora. It is formed of crystalline limestone, standing nearly vertically and intruded by granite.

There are many other scattered areas of limestone and other sediments north and east of Hermosillo in the region of Ures, beyond the area I studied. Many of these probably are of Paleozoic, and mostly Permian age, though Liassic and Neocomian fossils have been found in several places.

"Juratrias" (Barranca group).—This is a thick group of clastics, largely of fresh- or brackish-water origin, containing beds of coal and graphite. Because of its excellent exposures in the vicinity of La Barranca, east of San Javier, Dumble named it the Barranca group. As indicated by Dumble (op. cit., pp. 139-140), the group is divided by a thin-bedded sandstone and carbonaceous shale. It is the most widespread sedimentary unit of the region.

The type region of the Barranca group is the Sierra de San Javier, the high range lying along the west side of the Río Yaqui (Fig. 2). The sedimentary sequence there is obscured by the complex faulting, shattering, and intrusion which the beds have undergone. There are two places where the succession of beds is relatively unbroken through a great thickness of section—in the valleys draining east from La Barranca and in the high Aguja chain of peaks between San Javier and La Barranca. In those places the sequence is well over 1,000 meters in thickness, comprising grey, buff-weathering massive sandstone, generally quartzitic, which contains members of shale and thin-bedded sandstone, having seams of coal and graphite. The coal is soft and crumbly, but has been mined for use at the silver mines of San Javier.

The Sierra de Soyopa, the high range east of and parallel to the Sierra de San Javier, is almost wholly composed of the Barranca group, intruded by granitic rock. A number of small patches of badly shattered sandstone and quartzite, generally intruded by granite, occur in the Yaqui valley between the Sierras de Soyopa and San Javier, as well as south of the southern end of the Sierra de San Javier in the vicinity of Suaqui Grande. No fossils were found there, but lithologically the rock resembles the Barranca beds. The Sierra de

Tecoripa west of San Javier is a high range formed of thick, massive quartzite. The occurrence of graphite reported from there is evidence for placing it in the Barranca group.

The graphite area south of La Colorada was studied by Flores (op. cit., pp. 105-109). The lower members of the "Juratrias" succession there are black, grey, and yellow-brown shale, marl, sandstone, and quartzose and quartzitic conglomerate. The upper part is limestone or marly limestone, somewhat metamorphosed either by alteration to wollastonite or silicification of the limestone.

There are many ranges of quartzite and thin limestones north of Hermosillo near Santa Ana, from some of which Liassic fossils were collected by Flores.

I collected a number of cycad leaves in shaly beds of the formation in the Sierra de Soyopa east of Ónavas. These were determined by Professor Wieland to belong to a widely-distributed species, collected also by Wieland in the Rhaetic of Oaxaca. The coal-bearing member of the Barranca east of San Javier, in the type region of the group, contains abundant plant remains in certain layers. Twenty-four species of plants were identified by Newberry and listed by Dumble (op. cit., p. 139). Their age is said to be Rhaetic. West of San Marcial (Flores, op. cit., p. 107) there have been collected *Panope rémondi*, said to be of Rhaetic age, and species of *Pecten* referable to the lower or middle Lias. South of Santa Ana (Fig. 1) Flores found pectens, crinoids, bryozoans, and gastropods of Liassic age.

The Barranca group is the continental facies of Upper Triassic-Liassic sediments which probably were deposited over nearly the whole of Sonora, southern Arizona, and western Chihuahua. There is a gradual transition northwestward from the type area of the Barranca to a more marine facies. As noted above, limestones come into the section in the graphite mining area south of La Colorada, and marine or brackish water pelecypods are found there. North of Hermosillo, crinoids, bryozoans, and gastropods are also present. In the northwestern part of the State of Sonora, 45 kilometers west of Caborca (Fig. 1), the Permian limestone is overlain by 1,150 or more meters of sandstone and quartzite containing some layers of shale and limestone, from which was collected a prolific fauna of Karnic ammonoids, pelecypods, gastropods, *Spiriferina*, "*Orthoceras*," *Belemnites*, and ichthyosaurs. Above this lies 1,500 to 2,000 meters of

red micaceous sandstone, grey massive quartzite, and clayey sandstone and limestone. The limestone contains *Arietites, Belemnites*, pectens, *Mediola, Lima, Trigonia*, and *Pentacrinus*, of Lias age.[6] This is evidently a transition to the typical marine facies of the "Juratrias."

In view of the great lithologic similarity and similar stratigraphic position upon the Permian limestone (though the middle Cretaceous limestone is absent in Sonora), it seems reasonable to correlate the Barranca group and its equivalents in Sonora with the Glance and Morita formations of the Bisbee district (Fig. 1), though these have always been placed in the Lower Cretaceous simply because there is no apparent break between them and the overlying Cretaceous Mural limestone. The aggregate thickness of the Glance and Morita formations is 7,500 feet, comprising red breccia and conglomerate grading upward into red and buff sandstone and red shales. No fossils have been found in them. Though no fossil evidence can be brought forth to support such a correlation, the abundance of Upper Triassic and Liassic fossils in a similar thick group of strata not far to the south and southwest in Sonora strongly indicates that these beds are referable to that age.

Cretaceous? andesitic lava and agglomerate (Lista Blanca formation of Dumble?).—The Barranca sedimentary succession is overlain by dense dark-grey lava flows of andesitic composition separated from one another by indurated agglomerate. The lava commonly shows spheroidal structure, which may be due in part to pillow structure in submarine flows, though it is probably generally only the result of onion-skin exfoliation. In two places limestone layers were found interbedded in the lavas, but no fossils could be found there. The andesite is intruded by the granite batholiths of the region. Its thickness exceeds 1,000 meters, and in places may be much more. The andesite and agglomerate form high mountains contrasting strongly with the soft Tertiary agglomerate and porous andesites overlying it, which at most form low hills. In their typical expression it is easy to distinguish the two, but where only small areas of andesite occur it is difficult to know for sure to which group they belong, and the classification given on the accompanying map is in many places arbitrary. It is believed, though not proved, that the older group is intruded by the granite, while the younger was formed after the solidification of the batholiths.

[6] Information from unpublished letter by C. L. Baker to J. P. Smith, dated 16 August, 1925.

Dumble (op. cit., pp. 143-144), on the basis mainly of the section exhibited by the Lista Blanca range west of San Marcial (Fig. 2), concluded that the Barranca graded upward into the igneous group, which he termed the Lista Blanca formation and likewise assigned to the Jurassic. I did not study the San Marcial section, and at no place did I observe a transition between the formations, but because of the presence of limestone in the andesite and agglomerate group, I believe that it probably was formed during the Mesozoic marine cycle.[8]

There is Cretaceous limestone east of the area studied near Arivechi in the Sierra Madre. This is a southward extension of the Mural limestone of southeastern Arizona, for it contains fossils of the same type. Such limestone is not to be found west of the Río Yaqui.[9] Evidence has been brought forth in two other places in the Western Sierra Madre of this part of Mexico which tends to support my conclusion that this volcanic sequence is of Cretaceous age. Hovey[10] found at Guaynopita (Fig. 1) that the Cretaceous (?) limestone was overlain by an older group of andesite and breccia which had been folded conformably with it; these older folded formations were in turn overlain by nearly flat-lying younger dacite, rhyolite, and basalt. In the Cabullona basin of northeastern Sonora, Taliaferro[11] reports up to 800 feet of tuff and agglomerate which overlies more than 7,000 feet of Upper Cretaceous limestone, sandstone, and shale, and apparently forms a part of that practically conformable sequence.

Tertiary and Quaternary.—In most of the low-lying valleys in the eastern part of the region, between the sierras, there are belts of soft agglomerate, generally tilted at angles of 10-15°, which probably was laid down after the mountains had attained more or less their present form. It is doubtful if the mountain masses themselves were covered by agglomerate. However, in

[8] Flores (op. cit., pp. 114-115) states without explanation that the hornblende andesites in the region of La Colorada are all intrusive. While part of this rock is probably intrusive, the greater part appears to be definitely extrusive.

[9] Dumble records two localities of Cretaceous fossils in the central Sonora region—Cerro Cobachi and east of Zubiate. I visited both places, and could find no Cretaceous fossils, but in the beds which Dumble apparently considered to be of that age there were Permian fusulinids. North of Hermosillo near Santa Ana (Fig. 1) there is Cretaceous limestone, but this is of Neocomian age and therefore much older than the Mural.

[10] Op. cit., pp. 421-423.

[11] Taliaferro, N. L.: An Occurrence of Upper Cretaceous Sediments in Northern Sonora, Mexico. Jour. of Geol., 41 (1933), pp. 16, 31-32.

the west, in the Sierras de la Colorada and Cobachi, the agglomerate occurs within the range on the down-slope of tilted fault cuestas, and must there have been sheeted over the entire area. This agglomerate-lava group appears to be that which Dumble (op. cit., pp. 126-128) named the Báucari division after its exposures in the valley of the Cedros. However, he referred most of the agglomerate of the Yaqui valley near Tónichi to his "Nogales division," which he states lies unconformably beneath the Báucari there. I did not see the evidence for such subdivision.

The fault block cuestas in the region of La Colorada-Torres-Zubiate are formed of volcanics of this age (Fig. 2). The thickness seems to be variable. Around the mines of La Colorada the Paleozoic? metamorphic rocks are overlain by a flow of hornblende andesite, 30 meters of agglomerate, and 50 meters or more of rhyolite, the youngest flow of the region. This sequence seems to occur in the same order throughout the surrounding region, but appears to be much thicker in some of the ranges, such as the Sierra del Chivato south of La Colorada.

A still later phase of vulcanism is represented in a small basalt hill between Torres and Luján on the east side of the Southern Pacific line. In many parts of Sinaloa, Sonora, and southern Arizona similar basalts were poured out over the eroded scarps of the andesite ranges after the block-faulting of the region. They were emitted at such a late date geologically that their original surfaces are in many places preserved in their entirety (as between Ortiz and Guaymas, southwest of the region studied).

The several pediment levels are capped by coarse gravels. but these rarely exceed 10 meters in thickness. In valleys of graben origin, such as that north of Tecoripa, the alluvial fill may attain great thicknesses. Similarly, fault-block mountains like the Sierra de Cobachi are bordered by great alluvial fans. Proboscidean(?) bones were reported to me by the inhabitants from south of San José de Pimas (Fig. 2) and from Tepaguaje between Ónavas and Toledo. I did not have an opportunity to visit these places.

Dumble (op. cit., p. 125) observed Quaternary raised beaches in the Valle de Guaymas, extending within 15 kilometers of Ortiz, southwest of the area studied.

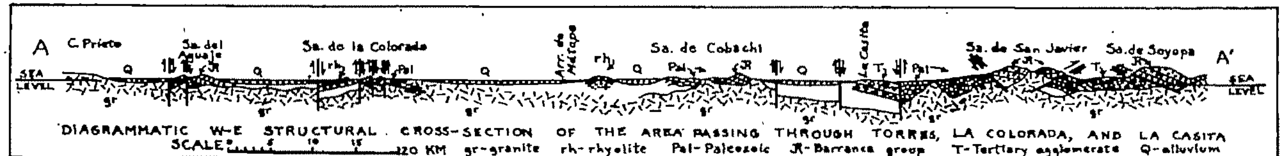

Fig. 3. Geologic sketch map of part of the Alamos district. For legend, see Fig. 2.

INTRUSIVE ROCKS.

The ranges of sedimentary and effusive igneous rocks are separated from one another by, and have their roots downward in, a vast batholith or group of coalescing batholiths of granite, of late Mesozoic or Tertiary age. This granite underlies most of the broad pediments of the region, such as that between La Colorada and Mazatán, and it also makes its appearance in the midst of the ranges of other rock (Fig. 2). Size of crystals and mineral composition are highly variable. Generally it is a coarse-grained rock consisting predominantly of quartz and feldspar, with a small amount of biotite. In the southwest part of the town of Mazatán the granite contains much muscovite. Along contacts there is a great deal of metamorphism.

Most of the other types of intrusive rock are probably to be regarded as differentiation products of the granite. A variety of igneous types is to be found in the vicinity of the mining districts, and it is probably in areas of much differentiation that the magma gave rise to mineralizing solutions.

As the granite is intruded into all formations older than the Tertiary agglomerate, it is believed that it is of early Tertiary or late Cretaceous age, the time of the Laramide orogeny.

STRUCTURE.

The ranges of sedimentary and extrusive igneous rocks are only detached roof-pendants in a vast granite batholith or group of coalescing batholiths (Fig. 3), probably representing the lowest parts of the roof of the batholith at the end of the period of intrusion, the higher parts having been removed by erosion. Nearly all the ranges of non-granitic rock are cut by apophyses of granite. The granitic intrusions have done much to complicate the pre-granite structure of the sediments and extrusives, giving rise to metamorphism and shattering along the contacts as well as a great deal of jointing and minor faulting at a distance from the contacts. It is probably for this reason that only the most massive, resistant formations, such as the Barranca formation, separated by 500 meters or more from the nearest granite contact, show the structure clearly. Successions of alternating competent and weak strata, such as the Paleozoic and parts of the Barranca (Jura-Triassic), show such a confusion of dips and are cut by so many small faults

that the working out of the structure and stratigraphy is extremely difficult.

In the eastern part of the area studied are the two longest unbroken ranges—the Sierras de San Javier and Soyopa. Both are made up mainly of Barranca quartzite, which is intruded by granite and its differentiation products. The Sierra de San Javier ends south of San Javier, and is succeeded in that direction by irregular andesitic mountains. The Sierra de Soyopa either ends or swings to the east between Onavas and La Dura, being likewise succeeded to the south by andesitic mountains. These ranges extend north between the Ríos Sonora and Moctezuma apparently without interruption into the Bisbee district of southeastern Arizona, and may be regarded as western flanking ranges of the Western Sierra Madre, in contrast to the detached ranges to the west. Their termination toward the south suggests an echelon relation to the main Sierra Madre.

Along the borders of these ranges the Barranca group and the Cretaceous (?) andesite and agglomerate lie in contact with the Tertiary andesite and agglomerate, and for a distance of 25 kilometers with the Paleozoic rocks of the Casita area. These contacts are not overlaps, for the Tertiary agglomerate in many places is dipping at low angles toward the greatly deformed Barranca beds. It is believed that the ranges are bordered by faults (Figs. 2 and 3). Patches of the Cretaceous (?) andesite and agglomerate group occur anomalously within the Sierra de San Javier, entirely surrounded by Barranca quartzite yet seemingly unrelated to it structurally, and tongues and outliers of Barranca quartzite occur beyond the borders of the range, where they show no relation to the structure of the surrounding rock. These seem to be explicable only as windows in, and outlying klippen of, an overthrust nappe.

If the structures of the Sierras de San Javier are explained by overthrusting, one is faced with several difficulties. Instead of an asymmetrical structure, with the overthrusting on one side and the roots on the other, the evidence of thrusting seems to be equal on both sides, and there are what seem to be windows in the very middle of the range. On the other hand, if it is postulated that the entire sierra is an outlier of a nappe with its roots to the east, this would necessitate a horizontal displacement of as much as 22 kilometers from the west side of the Sierra de Soyopa. To the west there is no range that could be regarded as the roots of such a nappe.

Overthrusts are known in the northern continuation of the same ranges on the north side of the Cabullona Basin near the Arizona border (Taliaferro, op. cit., pp. 35-36, Fig. 7). There the Naco, Glance, Morita, and Mural are overthrust to the southwest upon the Upper Cretaceous. Thrusting in the same direction is known in the Whetstone Mountains north of the international boundary. However, in the Bisbee district of Arizona, only 25 miles from the Cabullona Basin thrusts, there is strong thrusting from southwest to northeast. Determination of the direction and amount of movement on the thrusts in the Sierras de Soyopa and San Javier must await further field studies.

The areas west and south of the Sierras de San Javier and Soyopa are characterized by block-faulting, which took place probably after the intrusion of the granite. They are subdivided at about parallel 28°30′ into two regions of unlike geologic constitution. North of that line the ranges are predominantly sedimentary, comprising Paleozoic and Mesozoic strata. South of that latitude, beyond the area mapped as far as the coast, there are only a few patches of highly altered quartzite in a region dominantly igneous. The following are the main structural features of the northern area:

Tecoripa graben.—The straightest and longest valley in the region is that which extends from La Casita to Tecoripa, Suaqui Grande, and Cumuripa, where it reaches the Río Yaqui. North of Tecoripa it is mostly filled with alluvium, but near and south of that town it contains low-dipping Tertiary agglomerate in a belt averaging 4 kilometers in width, on each side of which are granite pediments and quartzite and andesite hills. On each side of the valley near Tecoripa there are hot springs along the granite-agglomerate contact. It is fairly certain that the valley has a graben structure. The bordering faults may extend north along the east side of the Sierra de Mazatán.

The Sierras de Cobachi and Tecoripa are divided from one another by a strip of granite pediment. On the east side of both ranges, facing the Tecoripa graben, there are fault scarps; on the west they seem to be tilted toward the Mátape valley.

Sierra de la Colorada.—From the La Colorada mining district north to Aguajito and beyond, there is a range of complex structure and great diversity of surface formations. The most striking structural feature of this range is revealed only beneath the surface in the mines of La Colorada and Minas

Prietas.[12] At depths of 800 to 1,000 feet in all the mine workings, granite is encountered below the quartzite, diorite, quartz porphyry, and metamorphic rock which contain the mineralized veins. It is separated from the overlying rocks by a plane of shearing, dipping about 15° to the southeast, along which there is much brecciation (Fig. 4). Where this granite comes to the surface north and northeast of Minas Prietas the fault plane can hardly be recognized as such at the surface exposures. Granite of the same composition also occurs above the fault plane southeast of Minas Prietas. The direction of movement along the fault plane is not known, though, lacking evidence to the contrary, it is presumed to be most likely from the direction in which the plane dips, that is, from the southeast toward the northwest.

The whole Sierra de La Colorada is cut by a number of block faults, formed after the extrusion of the rhyolite flow which is the youngest rock of the range. Block faults displace the plane of the overthrust in the mines at La Colorada. Most of the fault blocks are tilted toward the west, their scarps facing eastward. The range was up-arched in the last orogenic movement affecting the region, and the arch broken by normal faults. The ranges south of La Colorada are likewise westward-dipping fault cuestas.

Structural history of the region.—Dumble reported a structural break between the Lower Paleozoic and the Permian, but I was unable to locate this. In late Triassic and Early Jurassic time the State of Sonora was the site of a continually-sinking geosyncline in which several thousand meters of clastic sediments were deposited. It grades from a purely continental facies in the Yaqui valley to one with marine members in central and northwestern Sonora. Upon the sediments were poured a great thickness of andesitic lava, much of which probably solidified under the water. In Late Cretaceous time the whole region was folded and along the Río Yaqui nappes were developed. Probably at about the same time a great granite batholith or series of batholiths intruded the sediments and lavas. The portion of the area west of the Sierra de San Javier probably had low relief in Tertiary time, for it was sheeted over by agglomerate, finally capped by a flow of rhyolite. Then it was broken by normal faults, trending generally N. 15-20° W., forming fault blocks mostly tilted to the west.

[12] Information from Mr. W. C. Taylor, Jr., of La Colorada.

Probably from the fissures formed during this normal faulting basalt was poured out locally, as the last volcanic event in the region. At the same period the intermontane valleys between the high ranges in the Yaqui valley were filled with agglomerate alternating with some andesitic flows.

ECONOMIC GEOLOGY.

In the region studied there are hundreds of mineralized veins. The main commercial developments have been in the heart of areas with a great variety of igneous rocks—La Dura, San Javier, and La Colorada. Silver and copper values predominate in the ores, though La Colorada is an exception, gold values having been greatest during the period of operation. In 1932 no mine of any importance was being worked.

There are a number of places where placer gold occurs in arroyos and in the gravel terraces bordering the arroyos and the Río Yaqui. They are worked by crude methods by the natives of the region, but yield scarcely a living wage to them.

Coal was mined from the coal fields east of San Javier for operation of the silver mines. The ranges south of La Colorada contain seams of high-grade amorphous graphite which have played an important part in the world's production of that mineral.

Limestone of the Permian(?) is quarried east of Hermosillo for use in the manufacture of cement.

NOTES ON THE OCCURRENCE OF PALEOZOIC STRATA IN THE DISTRICT OF ALAMOS.

Paleozoic strata were first reported in the district of Alamos (Fig. 1) by Dumble (op. cit.), and were again studied by Angermann,[18] who fell into the natural error of believing that the Casita of Dumble was the ranch of that name on the bank of the Cedros, which lay on Dumble's route and is a place of much more importance than the Casita near which Dumble collected his "Silurian" fossils, and which lies between San Javier and Mazatán.

Paleozoic (?) rocks.—There are two principal areas of probable Paleozoic rocks in this region, one around El Trigo and

[18] Parer. Inst. Geol. de México, 1, No. 3, pp. 81-90, 1904.

the Trigo mine, and the other in the headwaters of the Arroyo Arenoso between Conocarit and Macoyahui (Fig. 4). At the first locality there are outcrops of quartzite interbedded with a lesser amount of altered limestone, so intensely shattered that bedding planes cannot be made out. I found no fossils here, but Angermann reported a poorly preserved brachiopod that seemed to be a *Spirifer*. At the head of the Arroyo Arenoso there is a range of hills trending northeast-southwest, made up

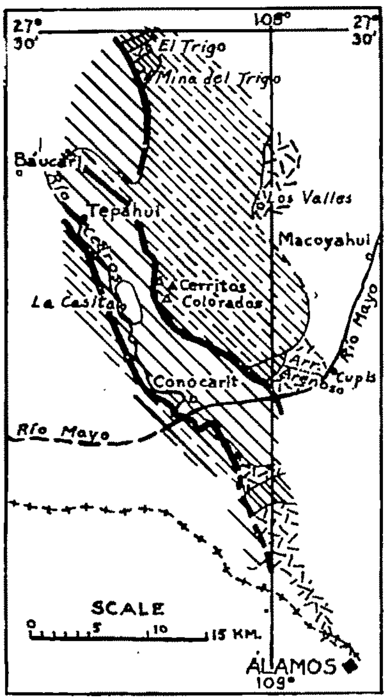

Fig. 4. Structural cross section along line A-A′ of Fig. 2.

of quartzitic sandstone and hard, granular limestone. In the float below this range there are abundant boulders of crinoidal limestone. About 4 kilometers northeast of the ranch La Casita, and midway between the Trigo and Arroyo Arenoso areas are the Cerritos Colorados, small outliers of altered limestone that may be assignable to the Paleozoic. They overlie a porphyritic intrusion. Angermann reports another locality from south of La Casita on the west side of the Cedros valley, where there are vertical limestone, quartzite, and quartzitic con-

glomerate. The few imperfect fossils in these altered strata do not permit exact age determination, but it is reasonably certain that they are Paleozoic.

Barranca (?) formation.—Northwest of Alamos there is an east-west range of red quartzite at the Piedras Verdes mine, intruded by granite. Lithologically it resembles the Barranca formation in a general way, and Angermann and Aguilera so assigned it, but Dumble regarded it as Archean.

Igneous complex.—A high massif between the Ríos Mayo and Cedros is composed of andesitic lava and agglomerate resembling the supposed Cretaceous volcanics of central Sonora.

Tertiary agglomerate[14] fills the valley of the Cedros, probably in a graben structure similar to that of the valley of Tecoripa in central Sonora.

Structurally this area is very similar to the western part of the region studied in central Sonora. The Cedros valley is a graben, bordered on both sides by older rocks. The western side of the valley is a range of andesitic rock. To the east is the high volcanic massif, around the borders of which are the three areas of probable Paleozoic strata, accompanied by more extensive areas of intrusive granite.

[14] Identified by Dumble as Triassic Lista Blanca but by Angermann as late Tertiary.

Iowa City,
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THE EXTRACTION OF RUBIDIUM AND CESIUM FROM LEPIDOLITE.

T. G. KENNARD[1] AND A. I. RAMBO.[2]

SUMMARY.

A method is described for the preparation of rubidium chloride and cesium chloride of high purity from lepidolite. Comparison is made with methods found less satisfactory. The amounts of rubidium chloride and cesium chloride obtained correspond to a content of 0.67% Rb_2O and 0.16% Cs_2O in the lepidolite.

I. *Occurrence of Rubidium and Cesium in Lepidolite.*

Rubidium was discovered in lepidolite from Saxony by Bunsen (6) in 1861, and has subsequently been reported to occur in various lepidolites from different localities in amounts ranging from traces to 3.73% rubidium oxide, Rb_2O. Cesium has been reported to occur in lepidolite in amounts varying from traces to 0.72% cesium oxide, Cs_2O. Lepidolite from the Stewart mine at Pala, Calif., is said to contain about 0.3% Cs_2O (17).[3]

While engaged in a spectroscopic examination of certain minerals, strong rubidium and weaker cesium lines were observed in the spectrum of lepidolite obtained from the Sickler mine at Pala. The extraction of rubidium and cesium salts was accordingly undertaken.[4] A preliminary announcement of the occurrence of rubidium in this lepidolite has been made elsewhere (11).

[1] Research Fellow in Chemistry, Claremont Colleges.
[2] Based on a thesis submitted to Claremont Colleges in partial fulfillment of the requirements for the degree of M.A. in Chemistry.

[3] For numerous references to the occurrence of rubidium and cesium in lepidolite, see Dana's System of Mineralogy, 6th ed., p. 624, and Doelter's Handb. d. Mineralchemie II, 2, 449, and III, 2, 106. Other occurrences have been observed.

[4] Since preparing this article for publication, there has come to the authors' attention an article by W. J. Schiefflen and T. W. Capon [J. Soc. Chem. Ind., 27, 549 (1908)] in which it is stated that during the preparation of lithia from Pala lepidolite, rubidium and cesium alums were obtained in one stage of the process. Schieffien and Capon do not state, however, that rubidium and cesium occurred in the lepidolite.

II. *Spectroscopic Control Methods.*

Throughout the extraction and purification of the rubidium and cesium salts, spectroscopic examination of the various fractions was regularly made. Both the arc and flame were employed for the excitation of spectra. The less volatile samples, such as the raw or fused lepidolite, and the residue remaining after the extraction of the alkalies, were subjected to arc excitation; the extracted salts, such as the alums, chlorostannates, and bitartrates, were customarily examined by volatilizing and exciting in the flame, since this method was quicker. The most sensitive spectral lines[5] for potassium, rubidium and cesium, when excited in the flame, are as follows: potassium, 7699.01 Å, 7664.94 Å (5); rubidium, 4215.58 Å, 4201.81 Å (12); cesium, 3593.2 Å, 4555.3 Å (12).

III. *Decomposition of Lepidolite.*

The grayish-white lepidolite, crushed to pass through a screen with five meshes to the inch, was fused in a small, gas-fired furnace. The interior of this furnace, cylindrical in shape, was 15 cm. in diameter and 21 cm. high. An iron pipe 35 cm. long, with an inside diameter of 3.2 cm. was bent to an angle of about 45°, and mounted in the furnace so that its ends projected slightly beyond the top and side wall of the furnace. Crushed lepidolite was poured into this pipe (at A, in Fig. 1), and the furnace started. Additional lepidolite was added at intervals, and gently tamped down. The temperature of the melted material within the central portion of the pipe, as measured by means of a thermocouple, was about 1090°, ± 10° C.; the surface temperature of the viscous, fused material as it was slowly extruded from the pipe (at B, in Fig. 1) was approximately 700° C. By this means 2.8 kg. of raw lepidolite could be fused per hour. Since the fused or sintered lepidolite is isotropic, whereas the original mineral is anisotropic, it was possible to check the completeness of heat treatment by means of a petrographic microscope. Complete fusion was not essential, since merely sintering the lepidolite so that it formed a coherent mass was found sufficient to cause the lepidolite to become isotropic and capable of being decomposed readily by dilute sulphuric acid. If the lepidolite

[5] The values for all wavelengths are those given in Kayser, "Tabelle der Hauptlinien der Linienspektra Aller Elemente," Julius Springer, Berlin, 1926.

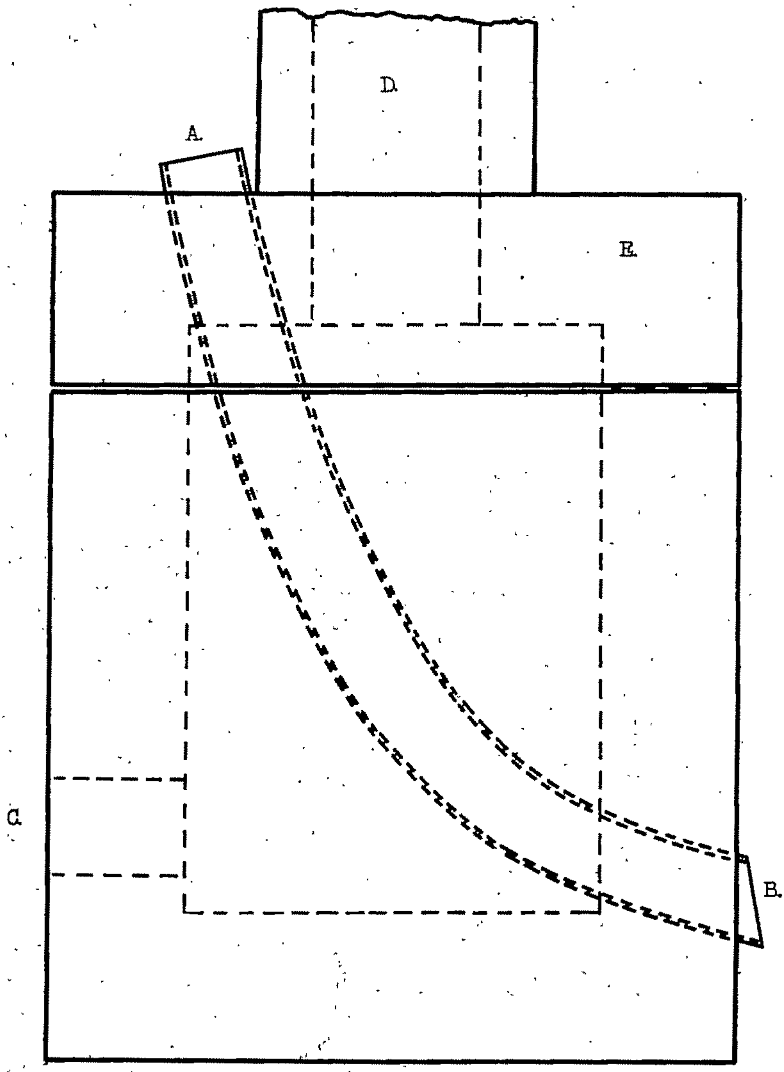

Fig. 1. Furnace.
AB—Iron pipe.
C—Tangential inlet for air and gas.
D—Vent.
E—Removable top.

was tamped too firmly into the pipe, the extruded mass contained a core of unaltered lepidolite, which was not completely decomposed by the subsequent treatment with acid.

In order to estimate the loss in weight on fusion, small samples of the raw lepidolite were ignited to constant weight in porcelain crucibles, heating to a bright orange. A loss in weight of 2.7% was found.

After being ground in a burr mill to pass a 40 mesh sieve, the fused lepidolite was decomposed with sulphuric acid. A typical run was as follows: 1 kg. of ground, fused lepidolite was suspended in a 5 liter, round-bottom flask with a total of 21. of water and washings from a preceding run. 850 cc. of concentrated, commercial sulphuric acid were slowly added.

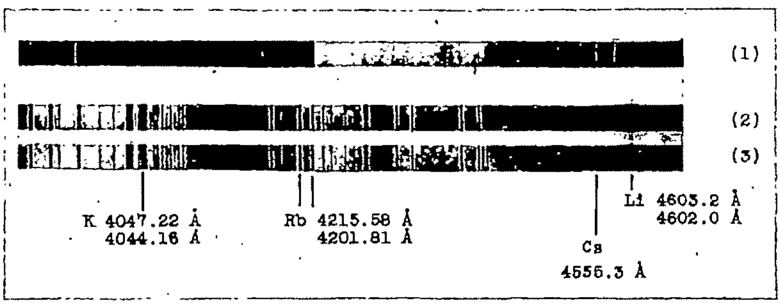

Fig. 2. (1) Spectrum of graphite electrodes. (2, 3) Spectra of raw lepidolite.

After the frothing subsided, the mixture was refluxed 45 minutes and immediately filtered, with suction. The residue was washed on the filter four times with 200 cc. portions of boiling water. The first filtrate was diluted with part of the washings to a volume of approximately 2.8 1., and was allowed to crystallize. The remainder of the washings was used in the next run.

By this method about 900 g. of alums were obtained per kg. of fused lepidolite. A spectroscopic examination of these alums revealed the presence of relatively large amounts of potassium and rubidium, a small amount of cesium, and very small amounts of sodium and lithium. The mother liquor from which the alums separated showed traces of rubidium, but no cesium. The washed residue was found to be spectrographically free from rubidium and cesium.

Other methods of decomposing the lepidolite were tried, but found to be less satisfactory. (a) The ground, sintered lepidolite was decomposed with hydrochloric acid (13), and the alkalies, together with iron and aluminum, were obtained as chlorides. Trouble was experienced in filtering, and in extracting the rubidium and cesium (8, 14, 19). (b) Ground, raw lepidolite was heated with concentrated sulphuric acid (10) until heavy white fumes ceased to be evolved. Another batch was refluxed two hours with 7 *N* sulphuric acid. In both cases decomposition was incomplete. (c) Raw lepidolite was decomposed with calcium fluoride and sulphuric acid (3, 4, 16) and also with sodium fluoride and sulphuric acid. Decomposition was complete in both cases, but the use of a fluoride was objectionable on account of fumes.

IV. *Concentration and Purification of Rubidium and Cesium Salts.*

Rubidium and cesium were concentrated from the alums obtained above by precipitating with stannic chloride (7, 18). The alums were dissolved in hydrochloric acid in the proportion of 1 kg. of alums to 440 cc. concentrated commercial hydrochloric acid diluted with 360 cc. water. The solution was heated to 95° C., and a slight excess of stannic chloride reagent, prepared by saturating concentrated hydrochloric acid with crystallized stannic chloride, $SnCl_4.5H_2O$, was added. The precipitate was allowed to digest while cooling slowly to 55° C. The crystals were then readily separated by decanting off most of the clear liquor, and filtering. A spectroscopic examination of this precipitate showed the presence of large amounts of rubidium and cesium, considerable potassium, and a little thallium. The mother liquor showed traces of rubidium, but no cesium. The precipitate was recrystallized from approximately 1 *N*. hydrochloric acid until no potassium lines were visible upon examination in the flame. The crystals of rubidium cesium chlorostannate, $(Rb, Cs)_2SnCl_6$, still contained a little thallium, as evidenced by the presence of the green thallium line.

The crystals were dissolved in water, and the tin and thallium were removed by precipitating with hydrogen sulphide. The resulting rubidium and cesium chlorides were evaporated with twice their weight of tartaric acid to a thick syrup, thus dispelling considerable hydrochloric acid. The

syrupy mass was dissolved in water, and rubidium bitartrate was crystallized out (1, 20). Since these first crystals showed traces of cesium, they were recrystallized from water until the cesium lines could no longer be seen. The rubidium bitartrate was readily converted to the chloride by charring, igniting gently, and extracting with dilute hydrochloric acid.

The mother liquor from the bitartrate recrystallizations was similarly converted to the chloride and filtered. The filtrate was evaporated nearly to dryness, and dissolved in the minimum amount of 3 *N* hydrochloric acid. A slight excess of a saturated solution of antimony trichloride disolved in 3 *N* hydrochloric acid was then added (9, 20). The precipitate of cesium antimony chloride showed traces of rubidium, and was recrystallized from 3 *N* hydrochloric acid until the rubidium lines could no longer be seen. Pure cesium chloride was obtained from the antimony double chloride by the usual method. The mother liquor from the cesium antimony chloride recrystallizations was reworked to obtain additional rubidium bitartrate, after first removing the antimony by hydrolysis and hydrogen sulphide.

A total yield of 89.1 g. of rubidium chloride, spectrally free from cesium and potassium, and 19.8 g. of cesium chloride, spectrally free from rubidium and potassium, was obtained from 10 kg. of sintered lepidolite. In addition, 2.5 g. of mixed chlorides of potassium, rubidium and cesium were obtained from the residual mother liquors resulting from the chlorostannate and subsequent fractionations. This mixture showed, in the flame, the presence of a large amount of potassium, a small amount of rubidium, and a trace of cesium.

Other methods of separating and purifying the rubidum and cesium were tried. (a) The crude alums were fractionally recrystallized (3, 4, 16). Twelve recrystallizations were needed to obtain a rubidium cesium alum spectroscopically free from potassium. Twenty-one recrystallizations were needed to obtain a second crop of crystals of equal purity from the mother liquors. No attempt was made to obtain a pure cesium alum from the potassium-free rubidium cesium alum. The fractionation of the alums was found much more laborious and time consuming than the chlorostannate method of purification. Both the alums obtained from sintered lepidolite which had been decomposed with sulphuric acid, and those from raw lepidolite decomposed with sodium fluoride and sul-

phuric acid were readily recrystallized. However, when calcium fluoride was used instead of the sodium fluoride, a little calcium sulphate accompanied the alums, and a certain amount of difficulty was encountered in the recrystallizations. (b) An attempt was made to precipitate the rubidium and cesium as the triple nitrite, $(Rb, Cs)_2NaBi(NO_2)_6$ (2, 15). Difficulty was encountered due to excessive frothing, even though sodium hydroxide had been added to the alums to reduce the acidity. The precipitate contained considerable potassium. Three reprecipitations were needed to obtain a product spectroscopically free from potassium. (c) An attempt was made to separate rubidium chloride and cesium chloride from potassium chloride by means of alcohol and hydrochloric acid (8, 14, 19), using the salts resulting from the decomposition of sintered lepidolite with hydrochloric acid (13). Difficulty was encountered, both in extracting most of the rubidium chloride from the large amount of potassium chloride, and in obtaining a rubidium cesium chloride concentrate free from potassium.

V. *Rubidium and Cesium Content of Pala Lepidolite.*

The quantities of rubidium chloride and cesium chloride extracted from the lepidolite correspond to the following calculated percentages of oxides in the raw material: Rb_2O — 0.67%; Cs_2O — 0.16%.

The actual rubidium and cesium content of the lepidolite was probably slightly higher than this, since perceptible traces of rubidium were lost in the mother liquors from the alums, and from the chlorostannate precipitation. Also, a small amount of rubidium and a trace of cesium remained in the mother liquors left from the chlorostannate and subsequent fractionations.

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A LABORATORY STUDY OF AN UNUSUAL SERIES OF VARVED CLAYS FROM NORTHERN ONTARIO.

GORDON RITTENHOUSE.

ABSTRACT.

In this paper the writer presents the results and certain conclusions from laboratory study of an unusual series of varved clays from the Wabigoon valley in northwestern Ontario. Seventy-four samples of the summer fractions and ten samples of the winter fractions below, through and above the unusual series were subjected to mechanical analysis by the pipette method. Analyses of carbonate and iron content were made of representative varves. Three hypotheses of origin are presented. The writer concludes that the unusual series resulted from a drainage across the area studied, probably from a distant source to the southeast or east. Other points dealing with the sedimentation and history of the region are briefly discussed.

INTRODUCTION.

Late-glacial varved clays deposited in a pro-glacial lake, possibly an eastern extension of Lake Agassiz, in the Wabigoon valley, District of Kenora, Ontario, have been extensively studied by the writer. Pits were dug in wave-cut exposures at sixteen localities and the thickness variations of the annual layers were measured and plotted after the method of DeGeer.[1] Correlations were established between most of the localities and three normal curves recording 400, 850 and 435 years of glacial retreat were constructed.

The longest normal curve is divisible into four parts: (1) a lower 300-year series of varves diminishing in thickness and recording ice retreat from the region; (2) a 140-year series increasing in thickness; (3) a 24-year series of very thick varves with very thick, dark chocolate-red winter fractions; (4) an upper series of approximately 360 years of diminishing thickness, signifying a resumption of normal retreat conditions. The upper division passes by degrees into homogeneous, thinly laminated, non-varved clay.

The third series is the most marked and peculiar. In this series of 24 varves (+ 1 to + 24, Fig. 2) the variation in thickness is a function of the thickness of the winter fractions. The winter fractions are dark chocolate-red in color and vary in thickness from 1.5 to 6.8 cm. The summer fractions are dirty chalk-white in color and vary in thickness from .8 to 1.8 cm., averaging 1.4 cm. These varves will hereafter be termed "abnormal."

[1] DeGeer, G., "On the Solar Curve as Dating the Içe Age, the New York Moraine, and Niagara Falls through the Swedish Timescale," Geografiska Annaler, 8, pp. 280-281, 1926.

The term "normal" will be used to designate varves in which the variation in thickness is a function of the thickness of the summer fractions. The winter fractions are dark grey with a slight olive-green cast when wet. Varves 0 and + 25 to + 28 (Fig. 2) have winter fractions gradational in color between dark grey and dark chocolate-red. The summer fractions are dirty chalk-white and vary in thickness from .6 to 1.5 cm., averaging .9 cm. Fig. 1 is a photograph showing the relation of the normal and abnormal varves.

In an effort to determine the genesis of the abnormal series the writer undertook a laboratory study of samples collected above, through and below this series. The writer considered the following three hypotheses adequate to cover the problem of marked increase in thickness and of change of color.

1. The thickness and associated coloring of the abnormal varves were due to the increased melting of the ice contemporaneous with the retreat from the Hartman moraine, about seven miles north of the town of Dinorwic and crossed by the wagon portage between that town and Sandybeach Lake. Antevs[2] notes that abrupt changes in color are not infrequently noted in the winter layers of some of the varved clay deposits of eastern North America. Sauramo[3] notes that thick varves are deposited during retreat periods. Perhaps the combination of these two factors produced the abnormal series at Wabigoon.

2. The abnormal varves are contemporaneous with the halt of the ice front during which the Hartman moraine was deposited. Unusually severe weather conditions resulted in the freezing of the lake, which fronted the ice, to a great depth and concentrated the soluble salts and the clay in the remaining water of the lake past the critical point which would produce flocculation[4] and perhaps the precipitation of calcium carbonate. The temperature of the unfrozen water would probably be about the same as the temperature of the water during normal

[2] Antevs, E., Retreat of the Last Ice Sheet in Eastern Canada, Can. Geol. Surv. Mem. 146, p. 21.

[3] Sauramo, M., "Quaternary Varved Sediments in Southern Finland," Bull. de la Commission Geologique de Finlande, No. 60, p. 121.

[4] Antevs, E., "Varved Sediments" in Report of the Committee on Sedimentation, 1928-1929, Nat. Research Council Bull. 92, pp. 61-62. Antevs suggests that because of the "extremely slow rate of settling of minute particles in water . . . the bulk of the finest material in the winter layers of varved glacial clay underwent flocculation before going down." Antevs refers to the suggestion of Ragnar Ericson that the winter flocculation of the colloidal particles takes place because the water becomes slightly acid from the solution of finely ground rock material.

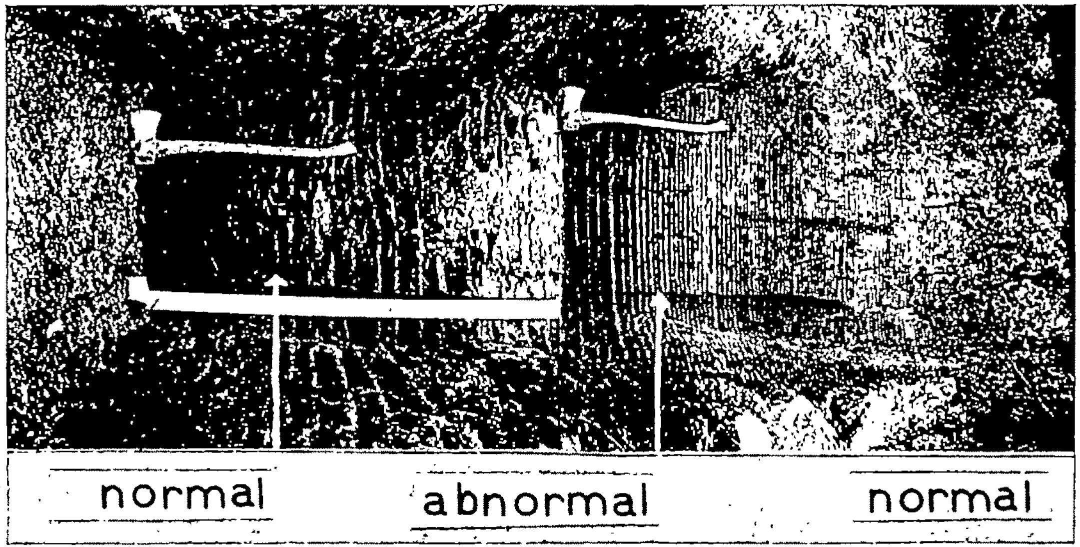

Fig. 1. Composite photograph showing relation between normal and abnormal varves.

winters and would not affect the amount of calcium carbonate in the solution through an increase in solubility.

3. The abnormal varves were due to a sudden influx of very fine material of different composition from some distant source, in other words a drainage.[5] The drainage may have been either the entrance of discharge from some large glacial lake or the opening of a new drainage channel directly from the ice front. If a drainage occurred, it was an unusual drainage, lasting six to eight times as long as those described by Antevs in eastern North America.

COLLECTION OF SAMPLES

The samples analysed for carbonate and iron content were collected by Dr. F. J. Pettijohn during the field season of 1929. The samples used for the mechanical analysis were collected by the writer during the field seasons of 1931 and 1932. All samples came from McKeevers Point, about a mile and a half southwest of the town of Dinorwic. The method of collection was the same in all cases. A pit was dug back into the wave-cut bank until undisturbed varves were reached. A vertical section was smoothed up and the thickness of the varves measured. Two to sixteen ounce samples were collected of both summer and winter fractions, care being taken to exclude all winter material from the summer fractions and vice versa. This necessitated removing a thin layer of material on each side of the summer and winter contact, but since all samples were collected in the same manner the element of error in the analyses from the loss of this discarded material was probably small.

CHEMICAL ANALYSIS

The writer is indebted to Mr. George Otto for the chemical analyses. The apparatus for the carbonate analysis was the same as that described by W. F. Hillebrand in the "Analysis of Silicate and Carbonate Rocks."[6] The carbonate was calculated as dolomite, $CaMg(CO_3)_2$. The Zimmerman-Rhinehardt method[7] was used for the analysis of iron. The iron was calculated as the ferric oxide. The results are shown in Table I. Samples numbered 24W, 31W and 31S are abnormal

[5] Antevs, E., Retreat of the Last Ice Sheet in Eastern Canada, Can. Geol. Surv. Mem. 146, pp. 19-20.

[6] U. S. G. S. Bull. 305, pp. 150-152, fig. 23, p. 151.

[7] Titration with a potassium permanganate solution after solution with hydrochloric acid after reduction with stannous chloride.

varves. Samples numbered 43W, 43S, 45W and 45S are normal varves corresponding to varves + 30 and + 32, Fig. 2. S and W indicate summer and winter fractions, respectively.

TABLE I.

	24W	31W	31S	43W	43S	45W	45S
Fe_2O_3 1.	8.0_4	7.8_4	2.8_3	7.0_8	3.0_0	7.4_5	3.1_3
2.	7.3_4	7.7_4	3.1_1	7.1_8	3.0_0	7.4_5	3.0_4
3.	6.6_1		2.9_9				
$CaMg(CO_3)_2$ 1.	15.4_0	15.5_2	5.9_6	8.9_2	8.2_7	10.9_2	9.1_8
2.	14.5_7	16.8_8	7.0_1	9.0_1	7.9_8	10.8_0	9.2_3
3.	15.8_1	16.9_7	6.7_7				
Best values							
Fe_2O_3	6.6	7.8	3.0	7.1	3.0	7.4_3	3.1
$CaMg(CO_3)_2$	15.6	16.9	6.9	7.0	8.1	10.9	9.2

The table shows that the winter fractions of the abnormal series have 5 to 9 per cent more carbonate than the winter fractions of the normal varves. The one analysed summer fraction of the abnormal varve series shows slightly less carbonate than the summer fractions of the normal series. The percentage of iron oxide, though less in the summer fractions than in the winter fractions of all varves analysed, remains constant in the normal and abnormal series. But the red coloring of the abnormal winter fractions apparently is due to the presence of the iron in the *ferric* state. In the summer fractions of the abnormal varves and both the summer and winter fractions of the normal varves, the iron presumably is present in the ferrous state.

How do these carbonate and iron analyses affect the three hypotheses outlined above? The first hypothesis is definitely eliminated. It assumes that the increase in thickness is due to increased melting and therefore an increased amount of fine material contributed to the glacial lake. It seems impossible that for a period of 24 years this fine material should be of a different chemical composition, and that this difference in chemical composition should be found only in the winter deposits. The quantity of material of different composition was very great and, by this hypothesis, must have been distributed very uniformly along an ice front at least 20 miles in length. The other two hypotheses are not adversely affected by the results of the chemical analysis.

MECHANICAL ANALYSIS.

The pipette method of mechanical analysis developed by Robinson,[8] Krauss[9] and others was used. For details and

theoretical treatment of the method see Krumbein's paper on the "Mechanical Analysis of Fine-grained Sediments."[10] Several minor changes were made to adapt the method for use with the Wabigoon clays. Briefly summarized the technique used is as follows:

Samples are air-dried at room temperature, quartered to 15-25 gr. and dried to constant weight on a hot plate (temp. 75-85° C.). This sample plus .5 gr. Na_2CO_3 plus approximately 100 cc. of tap water is placed in a baby nursing bottle and shaken for about two hours in a machine similar to that devised by Briggs, Martin and Pearce.[11] Then the sample is washed through a 1/16 mm. screen. The material on the screen is dried and weighed. Since this material was found to be essentially all organic matter (roots, etc.), concretions and undisintegrated clay and silt pellets, this weight is subtracted from the weight of the original sample.

The material below 1/16 mm. is diluted to 700-900 cc., heated to boiling, cooled, diluted to exactly 1,000 cc. and allowed to come to room temperature. Then the suspension is shaken vigorously for 1 min. (more if necessary) and allowed to settle for 7 min. 40 sec. A pipette is inserted to a depth of exactly 10 cm. and 20 cc. of suspension is withdrawn, evaporated to dryness in a 50 cc. tared beaker of known weight and weighed. Seven minutes of settling time allows all particles having a settling velocity equal to that of a sphere of quartz 1/64 mm. in diam. to settle below the 10 cm. depth. The evaporated sample contains a full concentration of material below 1/64 mm. equivalent diameter but none above that diameter. The 20 cc. sample is 1/50 of the original suspension. Therefore,

$$\frac{A - 50B}{A} = C$$

where A = Total weight of clay and Na_2CO_3 in the original suspension,
B = Weight of material finer than 1/64 mm. in 20 cc. extracted,
C = Per cent of material greater than 1/64 mm. equiv. diam.

[8] Robinson, G. W., "A New Method for the Mechanical Analysis of Soils and Other Dispersions," Jour. Agric. Sci., vol. 12, pp. 306-321, 1922.

[9] Krauss, G., "Ueber eine . . . neue Methode der mechanischen Bodenanalyses"; Int. Mitt. fur Boden kunde, vol. 13, pp. 147, 160, 1923.

[10] Krumbein, W. C., "The Mechanical Analysis of Fine-grained Sediments," Jour. Sed. Petrology, vol. 2, pp. 140-149, 1932.

[11] Briggs, L. J., Martin, F. D., and Pearce, J. R., "The Centrifugal Method of Mechanical Soil Analysis," U. S. Dept. Agric., Bureau of Soils, Bull. 24, 1904.

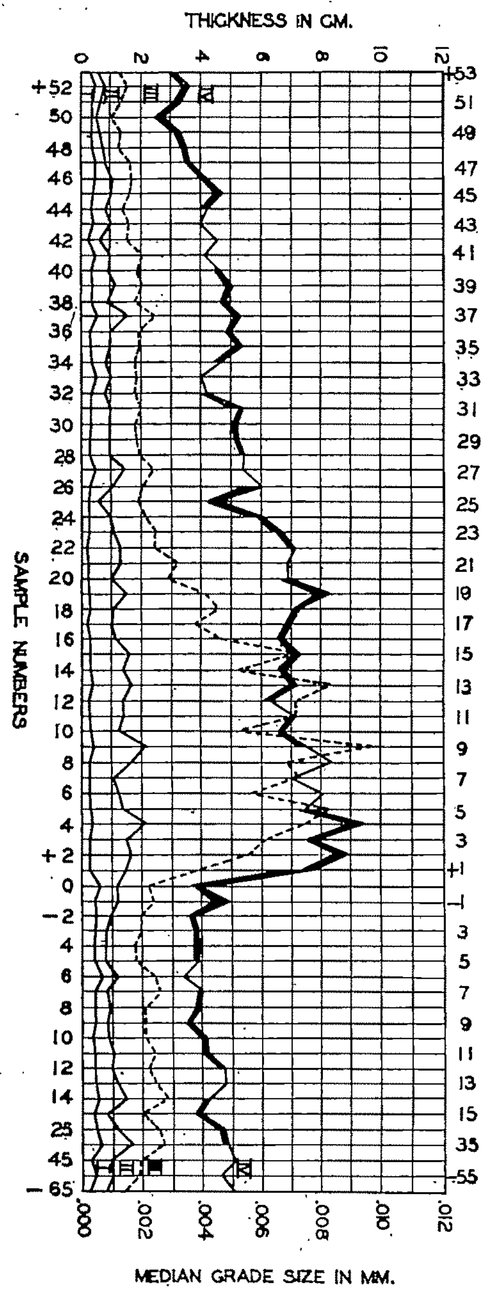

Fig. 2. I—Amount of material less than 1/250 mm. equiv. diam.; II—Thickness of the summer fractions; III—Total thickness of the varves; IV—Median grade size. Shading shows correspondence to Curve II.

The same process is followed to determine the amount of material above 1/128, 1/250, 1/500, 1/1000 and, if necessary 1/2000 mm. equiv. diam. The suspension was shaken before each period of settling (the writer has since found by empirical experiment that these shakings are not necessary). The 1/128, 1/250 and 1/500 mm. grades require 30 min. 41 sec., 1 hr. 43 min. and 7 hr. 43 min., respectively, for a settling depth of 10 cm. The 1/1000 and 1/2000 mm. grades require 15 hr. 36 min. and 62 hr. 24 min., respectively for a settling depth of 5 cm.

TABLE II.

MECHANICAL ANALYSES OF VARVED CLAYS

SUMMER FRACTIONS

	119S	142S	154S	155S	166S	178S
> 1/64	1.8	.6	.9	5.7	8.7	3.1
1/64 –1/128	13.8	15.8	12.9	42.1	45.2	26.4
1/128–1/250	40.8	40.7	36.4	33.2	28.4	41.0
1/250–1/500	26.0	23.9	26.2	11.1	11.3	19.2
1/500–1/1000	9.9	12.6	14.4	4.6	3.4	5.5
< 1/1000	8.0	6.3	9.3	3.2	2.8	4.6
	100.3	99.9	99.8	99.9	99.8	99.9

WINTER FRACTIONS

	154W	161W	166W	177W	179W	193W
> 1/64	4.2	...	5.9	4.4	6.7	4.4
1/64 –1/128	5.2	3.2	2.8	7.0	4.4	...
1/128 –1/250	6.0	3.8	3.0	6.2	10.0	1.5
1/500 –1–1000	...	2.2	1.9	...	...	2.8
1/500 –1/1000	20.7	4.4	26.0	20.1	22.3	28.2
1/1000–1/2000	20.2	14.5	...	28.8	21.2	21.5
< 1/2000 or 1/1000	44.5	71.9	60.5	33.5	34.7	40.9
	100.4	100.0	100.1	100.0	98.7	99.3

It was found that the material in the winter fractions of the varves was so fine that it was impossible to get characteristic curves. In most cases more than 60 per cent of the material was finer than 1/1000 mm. After more than 28 hours of settling these samples tended to flocculate. In addition there seem to be very little difference in the mechanical composition of the winter fractions of the abnormal and normal series. Some analyses of the winter fractions are shown in Table II. The summer layers did show striking differences in mechanical composition and were plotted as follows:

The curves of cumulative percentages of material above the different grades were plotted on a coördinate scale. The median grade sizes of the samples were read directly from the

curves. The median grade size is considered a true index of the variations between samples.

In Fig. 2, the median grade sizes of the samples are compared to the total thickness and to the thickness of the summer fractions of the varves. The I curve represents the actual amount of clay material (less than 1/250 mm. equiv. diam.) existing in the different varves. This figure was derived by dividing the actual thickness of the summer fractions of the varves by the per cent of material below 1/250 mm. equiv. diam.

The following relations were found to exist between the curves.

1. There is no varve-for-varve correspondence between the fluctuation in the median grade size and the fluctuation in the total thickness of the varves.

2. However, at varve + 1, Fig. 2, the median grade size almost doubles and continues at about that size through varve + 24. The abnormal series begins at varve + 1 and ends at varve + 24. There is a gradational change above varve + 24 in both the varve character and the median grade size.

3. The correspondence between the fluctuation in median grade size and the thickness of the summer layers is about 70-75 per cent. The correspondence between the fluctuation in median grade size and the thickness of the summer fractions of the abnormal series is 75-80 per cent. These are real correspondences; not the result of coincidence. The fluctuations in the median grade size curve are real fluctuations and not due to experimental errors as was shown by check analyses.

4. The curve representing the amount of clay material in the summer fractions of the varves, shows that there is less clay quantitatively in the summer layers of the abnormal varves despite the fact that the thickness of the summer fractions of the abnormal varves averages .5 cm. or half again as thick as the summer fractions of the normal varves.

CONSIDERATION OF THE REMAINING HYPOTHESES.

How do the facts outlined above affect the two remaining hypotheses? It seems logical to assume that severe or longer winters would be accompanied by somewhat cooler or shorter summers. If this assumption is correct, it seems impossible that both the thickness and the average size of material of the summer layers should increase. If the foregoing assumption is incorrect and normal summer temperatures existed, the pro-

portion of clay in the abnormal and normal varves should be approximately the same. But this is not the case. Not only is the proportion of clay in the summer portions of the abnormal varves reduced, but the actual amount of clay is less than in the summer fractions of the normal varves, even though the former are on the average .5 cm. thicker or approximately half again as thick as the latter. Hence the hypothesis postulating unusually severe weather conditions seems to be definitely ruled out.

How do the results of the laboratory study bear on the remaining hypothesis, which postulates a drainage through the area? The chemical analyses indicate that the source must have been in an area where the ice furnished material fairly high in carbonate and *ferric* iron, in other words, ice which probably deposited a red-colored, somewhat calcareous drift. The fine character of the material indicates that the source was distant.[12]

The writer first considered the possibility of a drainage of Lake Agassiz. Antevs[13] and Upham[14] believed that Lake Agassiz did at one stage drain eastward toward Lake Superior and Antevs located the most probable route near Neteianga Lake and Sioux Lookout, about 35-40 miles to the northeast of the Hartman moraine. But so far as the writer has been able to determine from the literature, there is no source of red material nor any red drift in the Agassiz basin.[15] Further-

[12] Antevs, E., Retreat of the Last Ice Sheet in Eastern Canada, Can. Geol. Surv. Mem. 146, p. 20.

[13] Antevs, E., Late-glacial Correlations and Ice Recession in Manitoba," Can. Geol. Surv. Mem. 168, p. 15.

[14] Upham, Warren, Glacial Lake Agassiz, U. S. G. S. Mon. 25, 1896, pp. xxiii, 443.

[15] In his recent Prof. Paper 161, Leverett points out that over a considerable area in Minnesota a grey drift sheet overlies a red drift of Wisconsin age and states that the Patrician ice depositing the red drift had retreated to a position near Vermilion Lake in Minnesota before the culmination of the Keewatin ice sheet which deposited the young grey drift. The boundary of the latest grey drift continues westward from Rainy Lake to the Lake of the Woods and then probably swings northward. In front of which sheet were the Wabigoon clays deposited?

Striae in the area between Rainy Lake and Lac Seul and Lake St. Joseph trend northeast. It seems impossible that grooving oriented consistently in this direction over such a wide area could have been formed by ice advancing from the Keewatin center. The striae known to be asociated with the deposition of the red drift farther east also trend northeast.

But the drift in the area studied by the writer is grey and contains no carbonate pebbles, being therefore, lithologically different from both the latest grey and the red drifts. It seems most probable to the writer that the non-calcareous grey drift of the Wabigoon area was deposited from a portion of the Patrician ice which, because of its westward extent, did not cross the source region of the red material. But this does not entirely eliminate the possibility of a third ice sheet.

more the abnormal varve series is thickest and best developed in the northeast section of the area studied and thinner at Dryden, 20 miles to the west. But there is a source of red, possibly calcareous material in the red drift to the east and southeast. A drainage from the east or southeast seems to be the most logical solution of the problem.

We have already noted that the distance of the drained area must have been great. Whether the drainage was due to a lowering of the outlet of a large glacial lake to the east or southeast or whether it was due to the deflection of drainage direct from the ice is not known. A lake is strongly suggested by the asymmetrical character of the abnormal series.

The deposition in the Wabigoon valley was affected in an unusual way. As noted above, the amount of fine material in the summer fractions of the abnormal varve series is quantitatively less than in the summer fractions of the normal varves. The currents resulting from the inflow of water were not only swift enough during the summer to carry out of the lake the fine material brought in from the drained area, but also some of the fine material resulting from the local melting. These currents were apparently not able to carry material larger than 1/250 mm. equiv. diam. in size. Material larger than this was deposited.

SUMMARY.

Unusual conditions of deposition existed in the Wabigoon valley for at least 24 years during late-Wisconsin time. During this time the writer believes that material derived from a distant source to the east or southeast was carried into the Wabigoon area. Chemical and mechanical analyses of the varved sediments seem to support this hypothesis. In addition these analyses contribute new information about the chemical and mechanical composition of varved sediments. The writer believes that this paper illustrates the value of chemical and mechanical analyses of sediments in supplying additional data which may support or eliminate suggested hypotheses of the origin of sediments.

University of Chicago,
Chicago, Illinois.

A NEWLY MOUNTED SPECIMEN OF *PORTHEUS MOLOSSUS* COPE.

MALCOLM RUTHERFORD THORPE.

(Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn., U. S. A.)

A magnificent skeleton (Fig. 1) of the primitive Cretaceous teleostean fish *Portheus molossus* has been recently mounted and placed on exhibition in the Great Hall of the Peabody Museum of Natural History. This piscine fossil, more than 15 feet long, is another of the great number of remarkable specimens of extinct forms of life collected by members of the Sternberg family, in this instance by Mr. George F. Sternberg, of the Fort Hays Kansas State College. The skeleton was discovered and exposed by Mr. Alfred E. Stude, a faculty member of the Wichita County Community High School, in the spring of 1932 in the south brakes of Butte Creek on the Berry homestead in Logan County, about 18 miles southwest of Russell Springs, and about 35 miles north of Leoti, Kansas.

The specimen, purchased by Yale University, was prepared and mounted by Mr. Fred Darby and Mr. H. S. Thompson. The left side of the fish is exposed, while the right remains imbedded in the matrix for the most part, and all of the bones lie exactly as they were found.

The entire vertebral column is present and consists of 87 articulated segments. The only parts restored are the majority of the neural spines, a few of the haemal spines, the entire dorsal fin, and part of the upper blade of the caudal fin.

While there are several nearly complete skeletons of this teleost known, there is but one better preserved and none with a finer skull so far discovered. The specimen is shown about 1/30 natural size in Figure 1. The total length is 15 feet 4 inches (4673 mm.), while that of some of the other known specimens is as follows: the one in the British Museum, nearly 14 feet; that in the American Museum of Natural History, 15 feet 8 inches, the largest so far described; that in the Fort Hays Kansas State College Museum, 13 feet[1]; the one in the public school at Oakley, Kansas, 13½ feet[1]; and the one, a composite, in the University of Kansas, probably a little under 13 feet.

Vertebral column. A few vertebrae in the anterior part are slightly rotated but not sufficiently to lengthen the column

[1] Written communication from Mr. G. F. Sternberg.

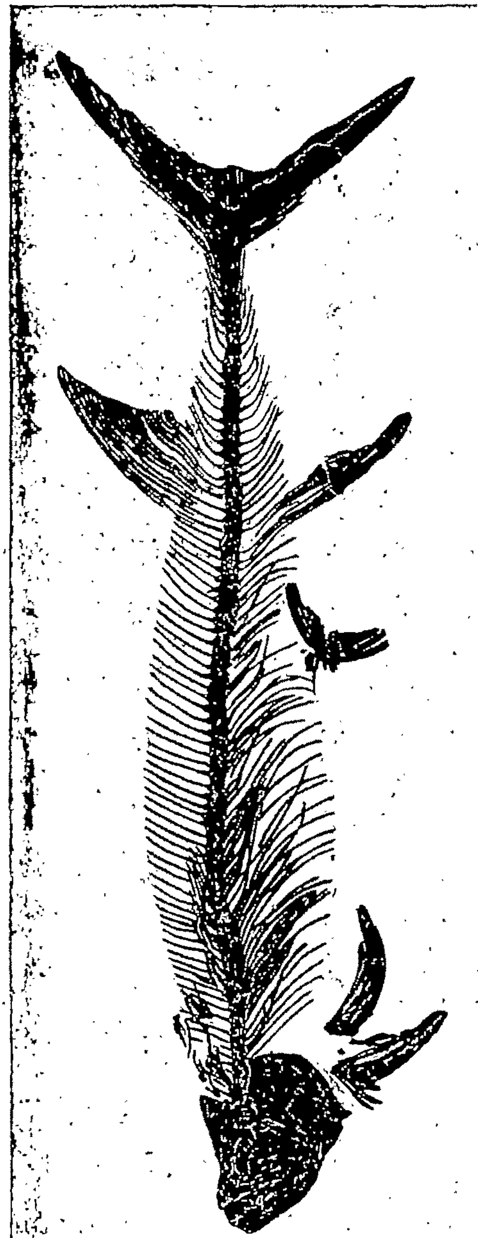

Fig. 1. Mounted specimen of *Portheus molossus* Cope. Position of dorsal fin conjectural; other fins as found in the rock. About 1/30 nat. size. Cat. No. 2177 Y. P. M.

beyond normal. There are 55 dorsals and 32 caudals. This compares with the specimens mentioned above thus: British Museum, D 55, C 33; American Museum, D 52, C 31; Fort Hays, D 57, C 33[2]; Oakley, D 55, C 28[2] (the caudals and the last 15 or 16 vertebrae here are from another individual, making it a composite mount); and the University of Kansas, D 52, C 27 approximately (this again is a composite mount). The majority of the vertebrae have but two deep longitudinal depressions, of which the upper is the larger, but V 7-V 11 inclusive have three nearly equal grooves. The centra are nearly uniform throughout the column, averaging 38 mm. wide and 64 mm. deep, but the segments of the anterior part and the extreme posterior part are not more than 32 mm. wide. The first parapophysis and rib are developed on the 5th vertebra.

Ribs. These are long, slender, gently arched, and medially excavated by a well-marked longitudinal groove. The upper end is expanded. Many are somewhat displaced, but remain exactly in their post mortem position. The parapophyses are like those in the British Museum specimen.

Skull. This part of the skeleton is complete (Fig. 2), with the exception of the posterior border of the opercular bone, and all bones are apparently in natural position, except for lateral crushing. Most of the sutures are partially obscured by what may be the impression of the skin, although no scales or scale impressions were found with or on this skeleton. The opercular and other bones are covered with irregularly spaced fine nodules, or coarse tubercles. The sclerotic plates are complete. The orbit is 89 mm. long and 64 mm. deep.

The mouth is partly open, and the length of the upper tooth-row is 11 inches (280 mm.). The anterior four teeth are long and strong, the maximum length being 49 mm. Posterior to these are 19 very much smaller teeth, the minimum length of which is but 3 mm. The maximum depth of the dentary is 102 mm. The seven branchiostegal rays are faintly outlined.

Paired fins. The pectoral fins, equal to about 16 vertebrae in length, consist of 4 rays, the anterior slender, the second about three times as wide and longer, while the third and fourth are larger than the first but less than one-half the size of the second. These are mounted as they lay in the rock. The second ray of the left (lower) fin measures 44 mm. in

[2] Taken from photographs sent by Mr. G. F. Sternberg.

width at the basal part, while that of the right is 64 mm. at the base, gradually tapering to 25 mm. wide at the distal end. These rays are considerably arched, more so than in the British Museum specimen, and the right more than the left. The slender anterior ray, so-called, may be the post-clavicle or

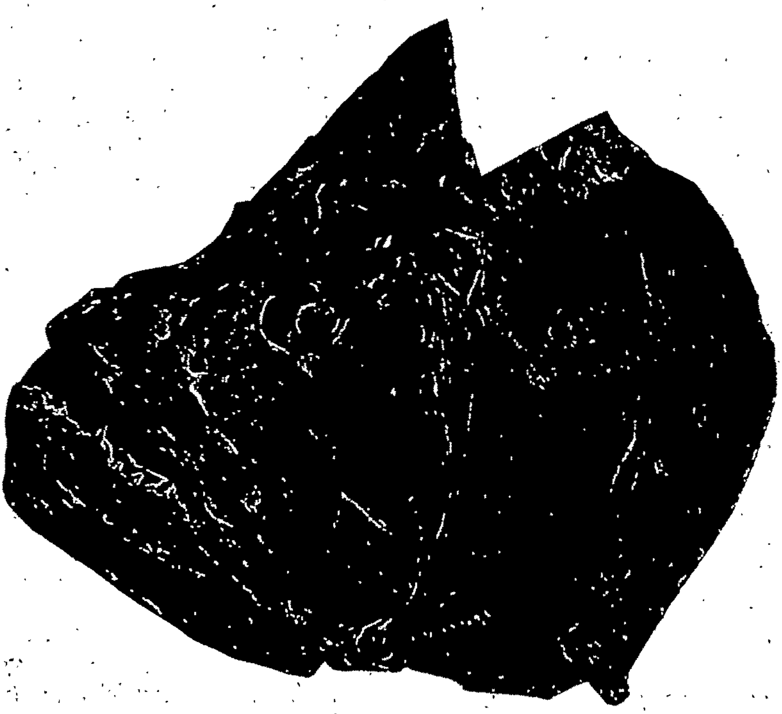

Fig. 2. Skull of mounted specimen of *Portheus molossus* Cope. Cat. No. 2177. Note sclerotic plates, teeth, and texture of bones. About 1/7 nat. size.

precoracoid folded back along the fin, or it may be the first ray, partly concealed by the second, and lacking its full length. The same structure is found in both fins, and the relationship is not clear.

These rays are bony rods, flattened on the outer surface, and somewhat striated longitudinally, probably marking structural fibres. There are no traces of transverse articulations. The

first and second have sharply rounded anterior borders, while in the others they are widely rounded. Except for the anterior ray, they resemble closely the comparable fins in the American Museum specimen.

Pelvic fins. Both fins are still attached to the firmly articulated pelvic girdle. They are approximately one-half as long as the pectorals, a proportion like that in the British Museum and Oakley (Kansas) specimens, but unlike that in the American Museum, University of Kansas, and Fort Hays Kansas State College Museum specimens. Each fin consists of not less than 10 rays, the outer two wide and of nearly uniform width throughout their length, thus differing from the British Museum specimen where the first is much the stouter and larger. The first is 32 mm. wide, the second 25 mm., and the third and fourth about 19 mm. wide. The others expand quite markedly outwardly from the pelvis. This again is unlike the British form. The right pelvic bone has 178 mm. of its length preserved and is similar to Hay's specimen. The outer ends apparently bear some skin impressions.

Unpaired fins. The anal fin, marking the beginning of the caudal series, is well preserved, the first interhaemal lying between V 54 and V 55 and extending below 7 vertebrae, V 62-V 69, and attached by 10 interhaemal rays. There is no evidence in this specimen to indicate that this fin extended as a low fringe backwards. There are 14 rays with some sculpturing or skin impression on the lower ends. This fin is not like the restoration used in the American Museum mount nor that in the University of Kansas.

The dorsal fin is entirely restored, with its first interneural between the third and fourth caudal. It emerges from the body above the fifth caudal. This origin is posterior to that of the anal, but it probably should be still farther back and not directly above the anal, as in the University of Kansas mount. There are no evidences of the size, shape, or number of the interneurals, and these have not been restored. Apparently no intermuscular bones are observable in the caudal or abdominal regions.

The caudal fin was deeply forked and powerful. The lower blade is nearly complete. There are 13 dorsal and ventral rays at the base, thus making the tail very symmetrical. The posterior rays become wider at the outer extremity. The upper blade is about three-quarters restored. Toward the distal tip of the lower blade are oblique striations, this sculpturing being suggestive of skin impression.

The last two or three vertebrae, rapidly diminishing in size, turn upward to make the homocercal type of tail. In the British Museum specimen the last five or six vertebrae are upwardly and backwardly directed. The hypural bones are restored, except for a nearly complete bone on the dorsal blade. It is triangularly shaped, the maximum dimensions being 102 mm. in length and 51 mm. in width. Additional strength for the tail is afforded by the sharp backward curvature of all of the posterior haemal and neural spines.

The Peabody Museum specimen is not composite. It contains a higher percentage of bone than any of the other above-mentioned specimens, with the exception of that in the British Museum; it is the second largest so far recorded; and it has the most complete skull extant.

Measurements.

	mm.	feet	inches
Total over-all length	4,673	15	4
Length of skull to posterior edge of operculum	735	2	5
Height of skull	621	2	½
Spread of tail	1,402	4	7 5/16
Length of left pectoral fin	571	1	10½
Length of right pectoral fin	602	1	11¾
Length of left pelvic fin	280	0	11
Length of right pelvic fin	304	1	0
Length of anal fin	456	1	6
Length of dorsal fin (maximum) restored	684	2	3

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CORRELATIONS BY RADIOACTIVE MINERALS IN THE METAMORPHIC ROCKS OF SOUTHERN NEW ENGLAND.

W. G. FOYE AND A. C. LANE.

PART I; BY W. G. FOYE.

INTRODUCTION.

The age of the rocks forming the Eastern Highland of Connecticut has long been a major problem in the geology of the State. No fossils have ever been found within the area.

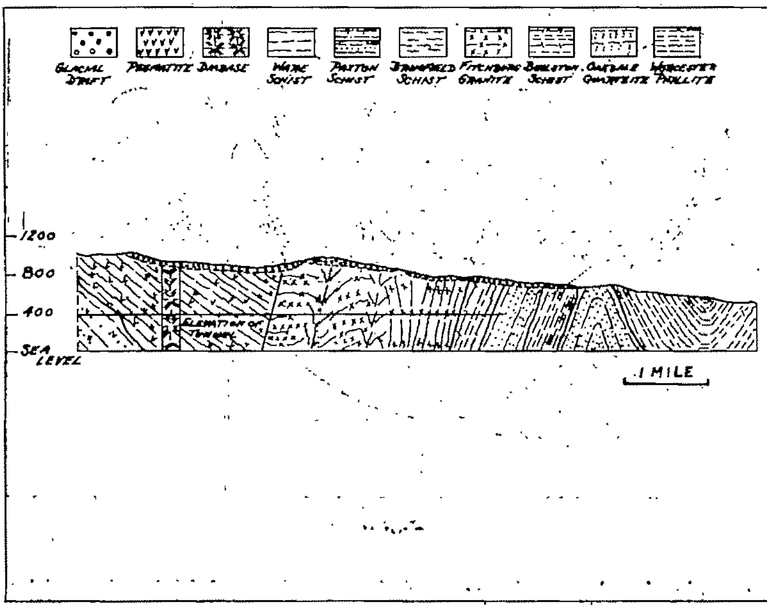

Fig. 1

The sedimentary rocks are highly metamorphosed by folding and granitization and the interpretation of their structures is exceedingly difficult. The Wachusett-Coldbrook water tunnel constructed by the Metropolitan District Water Commission has exposed a section 14.2 miles long through rocks of a like age in central Massachusetts, but the geologists of the tunnel, Doctor Charles P. Berkey and Frank E. Fahlquist, both admit that it has given them no direct evidence of the age of the rocks.

The section developed by this tunnel may serve as a typical section of the Eastern Highland of Massachusetts and Connecticut (Figure 1). There are three important members of the series: (1) a basal granitized schist, which is known as the Ware schist in Massachusetts and which resembles petrographically the Putnam series of Connecticut; (2) the Paxton schist, a quartz-biotite schist which is called the Hebron schist

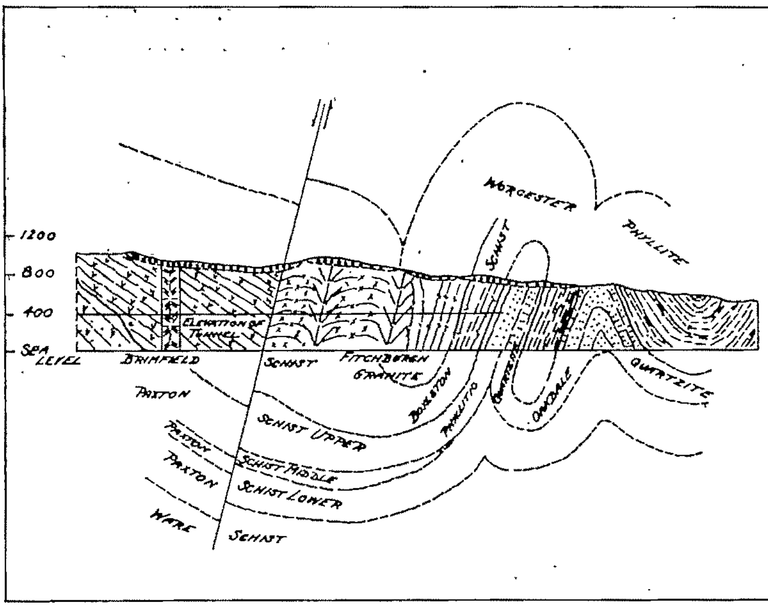

Fig. 2

or gneiss in Connecticut; and (3) the Brimfield biotite schist which frequently has accessory graphite, fibrolite, and staurolite and which is known as the Scotland schist in Connecticut.

Separated to the east from the areas wherein are exposed the three rock types mentioned above by a highly granitized belt known as the Fitchburg granite are belts of the Worcester phyllite and Oakdale quartzite. Pennsylvanian plants have been found in the Worcester phyllite and Professor Emerson[1] believed that the Brimfield schist could be correlated with the Worcester phyllite and the Paxton schist with the Oakdale quartzite. (See Figure 2.) But Doctor Berkey and

[1] B. K. Emerson, Bull. 597, U. S. Geological Survey, pp. 76-78, 1917.

Mr. Fahlquist have suggested that another interpretation is possible, making the Brimfield schist and the Paxton schist much older than the Worcester phyllite. (Cf. Figure 3.)

Similarly, to the west, the Brimfield-Paxton areas are separated from like rocks, known as the Amherst schist, by an elongate batholith of Monson granodiorite. Emerson traced the two series into one another in Warwick, north of Orange,

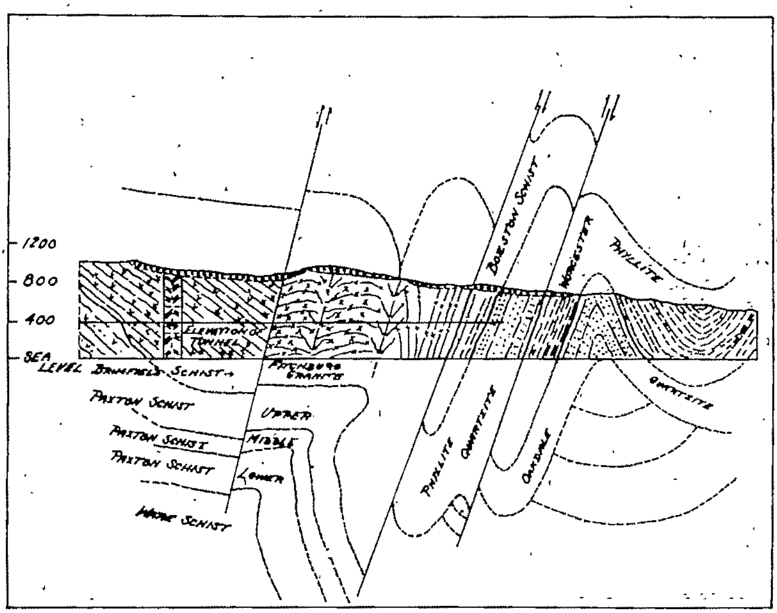

Fig. 3

Massachusetts, and stated that the Amherst was the equivalent of the Brimfield schist.[2] From observations made at Bolton Notch, east of Hartford, Connecticut, the writer believes that the Amherst schist (known as the Bolton in Connecticut) has been more closely folded and faulted than the Brimfield schist and contains included sections of the Paxton schist.

From this statement it should be apparent that any evidence on the age of the Bolton schist of Connecticut would aid in establishing the age of the larger areas of Brimfield and Paxton schists of Massachusetts and Connecticut.

[2] Bull. 597, U. S. Geological Survey, p. 73, 1917.

The Strickland Quarry.

The Strickland quarry is at Collins Hill, approximately at the center of the town of Portland, Connecticut. It is opened on a pegmatite dike which locally cuts the Bolton schist but

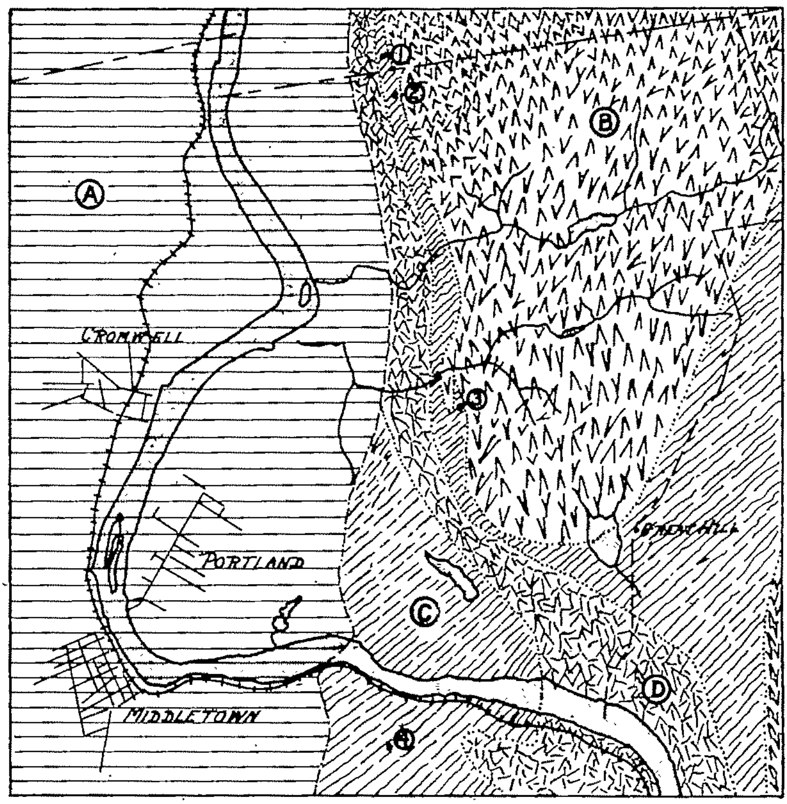

Fig. 4

1. Husband Quarry.
2. Hale Quarry.
3. Strickland Quarry.
4. White Rocks Quarry.

A—Triassic Red Sediments.
B—Monson Granodiorite.
C—Bolton Schist.
D—Maromas Granite Gneiss.

which is more generally infolded concordantly with the schist. It would seem as though the rocks were plastic during the period of injection, for the schist wraps about the pegmatite like a blanket.

The Bolton schist area varies from one-quarter to one-half

mile in width at this place and has an extension north-south of about ten miles. It lies between a batholithic mass of the Monson or Glastonbury (Haddam) granodiorite on the east and the Maromas orthogneiss on the west. The Maromas gneiss is believed to be analogous to the Sterling porphyroblastic gneiss of eastern Connecticut, which is the Monson granodiorite injected by the Carboniferous Sterling granite.

The pegmatite dikes of the Collins Hill area are distinctly connected with the Monson granodiorite and may be seen grading into this rock directly east of the Strickland quarry. The map (Figure 4) shcws the essential geologic facts con-

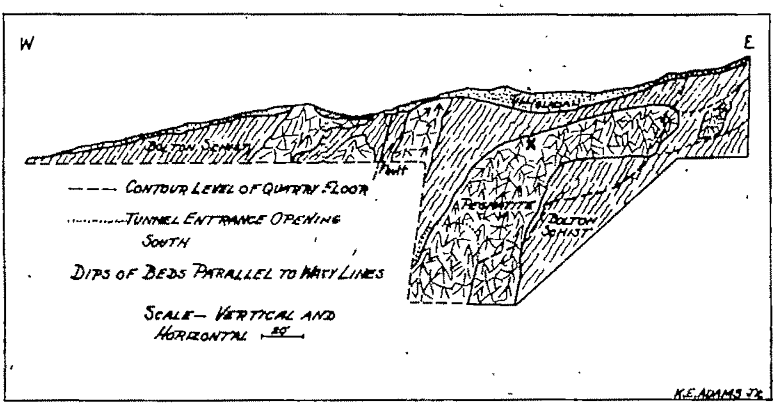

Fig. 5

cerning the area. A number of the feldspar quarries that have yielded uranium-bearing minerals are indicated on the map. It will be seen that they are located in the belt of the Bolton schist, adjacent to the Monson granodiorite.

An east-west section of the Strickland or Collins Hill quarry drawn to scale is shown in Figure 5. The cross indicates the approximate position of the uraninite crystals that were obtained from this dike. Frederick E. Strickland, who was managing the quarry at the time that the crystals were found, states that they were localized within a small area within a few feet of the contact, and no crystals were obtained outside of that area. Certainly no crystals have been found recently in the deeper portions of the quarry.

The uraninites analysed by Hillebrand[8] were obtained from the Hale quarry, Portland, near the Glastonbury boundary.

[8] W. F. Hillebrand, Bull. 78, U. S. Geological Survey, pp. 43-79, 1891.

In his article Doctor Hillebrand stated erroneously that the mineral was found in Glastonbury. This quarry was active between the dates of 1886 and 1895 and most of the uraninites obtained during that period came from this place.

The uraninites discussed in this article were obtained from the Strickland or Collins Hill quarry between the dates of 1913 and 1917.

The Committee on the Measurement of Geologic Time by Atomic Disintegration.

In 1923 a committee of the National Research Council of the National Academy of Science at Washington, D. C., was appointed under the chairmanship of Doctor A. C. Lane of Tufts College to study the relations between geological time and atomic disintegration. This committee has been very active in stimulating research along these lines and has accumulated a large amount of data. In February, 1932, Doctor Lane wrote to the writer, stating that the analysis of the uraninite from the Hale quarry, made by Doctor Hillebrand, suggested that the pegmatites from which they came are Devonian in age. He thought, however, that this data should be checked and asked for a number of small uraninite crystals that could be sent to the Radium Institute of Vienna for analysis.

Several crystals (2-5 mm. in diameter) showing the octahedral form slightly modified by the cube were selected and were sent to Doctor Friedrich Hecht of Vienna.

In the case of a uraninite crystal from the Strickland quarry four consecutive layers were analysed. The amounts of material used from the exterior to the interior shells were respectively 100 mg., 45 mg., 42 mg., and 21 mg.

The Analyses

The following three analyses were made from separate crystals from the Strickland quarry. The crystals from which analyses (1) and (3) were made weighed approximately 0.5 grams; that from which analysis (2) was made weighed 1 gram.

	1	2	3
Amount weighed	33 mg.	35 mg.	34 mg.
	%	%	%
Residue insoluble in acid	0.35	0.58	0.57
SiO_2 soluble	0.03	0.01	...
PbO	3.65	3.94	3.63
Pb (atomic weight = 206.05 ?)	3.39	3.65	3.36
SnO_2 (?)	...	...	...
Rare earths	0.36	0.28	0.36
ThO_2	3.80	2.59	3.78
Th	3.34	2.28	3.32
UO_2	67.13	75.41	73.59
UO_3	23.59	14.83	16.62
(U)	(78.81)	(78.82)	(78.71)
$Fe_2O_3 + Al_2O_3$	1.00	0.53	1.28
CaO	0.31	0.30	0.31
MgO	0.07	0.13	0.13
H_2O (-110°)	0.13	0.12	0.17
H_2O (110-300°)	Increase in weight in all 3 analyses		
Heat loss (300-1000°)	Increase in weight in all 3 analyses		
Totals	100.42	98.72	100.44
$\frac{Pb}{U + .36\,Th}$	0.042	0.046	0.042

The above analyses should be compared with those made by W. F. Hillebrand from a set of uraninite crystals obtained at the Hale quarry, Portland Connecticut.[4] The essential facts of these analyses are given in the following table.

	A	B	C	D	E
UO_2	59.13	58.01	59.31	57.43	59.93
UO_3	22.08	23.35	22.22	26.48	23.03
ThO_2	9.57*	9.78*	10.31*	9.79	11.10*
PbO	3.14	3.24	3.07	3.26	3.08
U	70.52	70.59	70.80	72.68	72.02
Th	8.41	8.60	9.06	8.61	9.76
0.36 Th	3.03	3.10	3.26	3.19	3.52
U + 0.36 Th	73.55	73.69	74.06	75.87	75.54
Pb	2.91	3.01	2.85	3.03	2.86
$\frac{Pb}{U + 0.36\,Th}$	0.040	0.041	0.038	0.040	0.038

Notes: * ThO_2 includes rare earths.
ThO_2 includes CeO_2.
In D the rare earths are $(Yt,Er)_2O_3 = 0.20$; $(La,Di)_2O_3 = 0.13$; $CeO_2 = 0.25$.
The ratios of A, C, and E, and to a less extent of B, would therefore be slightly low if calculated to three places.

It will be seen that, while the ratio of UO_2/UO_3 is approximately the same in the two sets of analyses, the total amount of uranium oxides is greater in the uraninites from the Strickland quarry. On the other hand the amounts of thorium oxide are greater in the uraninites from the Hale quarry.

[4] Bull. 78, U. S. Geological Survey, p. 62, 1891.

It has been suggested that the thorium content varies with the distance from the contact. The Strickland uraninites are known to have occurred close to the pegmatite-schist contact, but the crystals from the Hale quarry were not found in place and it is impossible to state whether or not their higher content of thorium is due to a greater distance from the contact.

If there has been much rearrangement of the materials of a crystal by leaching or otherwise, analyses of shells from the outer to the inner parts of the crystal should demonstrate the fact. Hence there is considerable value attached to the following analyses. They were made by Doctor Hecht from a single crystal weighing 0.614 g.

The crystal was dissolved in a warm solution of HNO_3 (1:2). Unfortunately during the first solution to obtain analysis A the gas evolution became violent and a part of the material was lost by spatter. This loss did not occur, however, during the solutions for the later analyses. The lead-uranium ratio is higher in analysis A than in the later analyses. Since it approximates the ratios in the set of analyses given on page 133 above, it is not probable that the loss by spatter is involved. Most analysts have found that small crystals of uraninite tend to have more lead than the larger crystals; hence the lead-uranium ratio is increased. The following analyses tend to indicate that the lead content increases in the outer shells of crystals.

	Exterior			Interior
	A	B	C	D
Used for analysis ...about	100 mg.	45 mg.	42 mg.	21 mg.
SiO_2 soluble	0.03%	0.03%	0.13%	0.39%
PbO	3.61	3.45	3.36	3.36
(Pb)	(3.36)	(3.20)	(3.12)	(3.12)
Fe_2O_3 Al_2O_3	0.72	1.16	0.85	1.40
Rare earths	0.70	0.33	0.73	2.13*
ThO_2	3.25	3.61	3.71	3.63†
(Th)	(2.86)	(3.17)	(3.26)	(3.19)
U_3O_8	94.50	94.57	92.98	16.08 UO_2 / 74.43 UO_3
(U)	(80.14)	(80.20)	(78.86)	(79.00)
CaO	0.18	0.28	0.30	0.32
MgO	0.00	0.004	0.04	0.02
H_2O (-110°C)	...	...	...	...
H_2O (110-300°C)	...	...	...	Increase in weight
Total	102.99%	103.43%	102.10%	101.76%
$\frac{Pb}{U + .36\,Th}$	0.041	0.039	0.039	0.039

* Probably a little too high.
† Probably a little too low.

The total sums of A, B, and C are as high as 102-103% because U is counted as U_3O_8. Analysis D shows that most of the U is present as UO_2. One has to subtract about 2.7% from the sums to get the real sums.

The lead-uranium ratios for the Branchville uraninites of western Connecticut average 0.052.[5] It is quite apparent that these minerals are older, probably having formed during the Taconic revolution 380 million years ago, whereas the Portland uraninites originated during the Acadian revolution approximately 290 million years ago. The Blueberry Mountain pegmatite, north of Boston, has associated minerals which give a lead-uranium ratio of 0.043.[6] It is therefore probable that the Dedham granodiorite is of the same age as the Monson granodiorite.

It should be stated that all these age determinations are based on the supposition that the lead contained in the analyses is derived from uranium and thorium and is not essentially contaminated by ordinary lead. This supposition may be incorrect, and the atomic weight of the lead should therefore be determined, but it would require a large amount of uraninite and expert work. No one has had the courage and material as yet to undertake the project!

The lead-uranium ratios from the inner shells of the single uraninite crystal from Strickland quarry as determined by Doctor Hecht suggest an age that is not far from the age of a monazite crystal from the same quarry determined by Doctor Fenner (278 million years).[7] The age may be obtained by substituting the appropriate values in a formula given by A. F. Kovarik.[8]

$$\text{Age} = \frac{\log [U + 0.360\,Th + 1.155\,(Pb\text{-}L)] - \log [U + 0.360\,Th]}{6.60 \times 10^{-11}}$$

U = mass in grams of uranium
Th = mass in grams of thorium
Pb = mass in grams of lead
L = mass of common lead in mineral

Since it is usually believed that no common lead is present in the mineral, the term L may be omitted. Substituting the

[5] The Age of the Earth, Bull. 80, National Research Council, Washington, D. C., p. 341, 1931.
[6] Bull. 80, National Research Council, Washington, D. C., p. 343, 1931.
[7] C. N. Fenner, This Journal, 5th series, v. 23, p. 331, 1932.
[8] Bull. 80, National Research Council, Washington, D. C., p. 99, 1931.

values obtained from the analysis of shell C, the following result is obtained:

$$\text{Age} = \frac{\log[78.86+0.36(3.26)+1.155(3.12) - \log[78.86+0.36(3.26)]}{6.60 \times 10^{-11}}$$

$= 289{,}800{,}000$ years.

PART II; BY A. C. LANE.

CALCULATIONS OF THE AGE OF THE URANINITES FROM PORTLAND, CONNECTICUT.

From my studies of the Wilberforce, Canada, uraninites it has been found that Kovarik's formula which Doctor Foye has utilized above to discover the age of the Portland uraninites may be simplified to the following form:

$$15{,}600 \log\left[1+1.156\left(\frac{\text{RaG}}{U_{238}}\right)\right]$$

In the monazite from the Strickland quarry analysed by Doctor Fenner there was no uranium present; hence the lead found was derived entirely from the thorium present.[9] From 7.489 grams of thorium 0.1007 grams of lead were derived. From this we may calculate how much lead was derived from the thorium in Hillebrand's analysis E (page 133). By proportion

$$7.489 : 9.76 = .1007 : x \qquad \text{and } x = .1312$$

Of the total lead (2.86 grams) in Hillebrand's analysis E, 0.1312 gram was derived from thorium, leaving 2.73 grams from other sources.

But according to von Grosse[10] 4 atoms of lead derived from actinium are present for every 100 atoms derived from radium. Hence deducting 4% of the remaining lead (2.73 grams), there are 0.11 gram of actinium lead present and 2.62 grams of lead of the atomic weight of 206 (i.e. RaG).

Substituting in the above formula

$$\text{Age} = 15{,}600 \log\left[1+1.156\times\frac{2.62}{72.02}\right]$$
$$= 281 \text{ million years.}$$

[9] C. N. Fenner, This Journal, 5th series, v. 23, p. 331, 1932.
[10] Phys. Rev., v. 42, pp. 565-570, 1932.

The formula based on thorium lead may be written as follows:

$$\text{Age} = 44{,}000 \log \left[1 + 1.115 \times \frac{\text{ThD}}{\text{Th}} \right]$$

From the above calculations it was shown that 0.1312 gram of thorium lead was derived from the 9.76 grams of thorium in Hillebrand's analysis E. Substituting in the formula, we have

$$t = 44{,}000 \log \left[1 + 1.115 \times \frac{0.1312}{9.76} \right]$$

hence t = 277 million years.

These ages agree so well that it is probable that the factor 15,600 used in the uranium formula above, and the factor 44,000 used in the thorium formula, are approximately correct. But their ratio

$$\left(\frac{15{,}600}{44{,}000} = .355 \right)$$

is the factor about which there has been some question in the lead-uranium ratio

$$\left(\frac{\text{Pb}}{\text{U} + \underline{\underline{0.36}}\ \text{Th}} \right)$$

It is probable therefore that 0.36 is the correct factor for minerals of this age, rather than the factor 0.25 used by some analysts.

Conclusions

1. The Strickland pegmatite dikes of Portland, Connecticut, contain uraninites that are approximately 280-290 million years old.
2. These dikes were injected probably during the Acadian revolution of late Devonian time.
3. The dikes are associated with the Monson granodiorite, which is also probably Devonian and is contemporaneous with the Dedham granodiorite of eastern Massachusetts.
4. The dikes are younger than the pegmatites of western Connecticut (Branchville), which are probably late Ordovician in age.

5. The Bolton schist which is intruded by the Strickland pegmatite dikes is older than Carboniferous. It can be correlated with the Brimfield schist of Massachusetts; hence the Brimfield schist is older than Carboniferous and cannot be correlated with the Worcester phyllite, which is known to be Pennsylvanian in age.

6. The factor 0.36 used by Kovarik in his lead-uranium ratio to show the relative rate of the development of lead from thorium as compared with uranium is probably correct.

MIDDLETOWN, CONNECTICUT.

VARIABILITY IN ARTIFICIAL FERROMAGNETIC IRON OXIDES.

LARS A. WELO AND OSKAR BAUDISCH.

Our chief purpose in collecting some and preparing most of the magnetites and ferromagnetic ferric oxides (gamma oxides) described in this paper was to secure a wide variety of material for our biochemical investigations. Both biological activity and magnetic properties are sensitive functions of the method of preparation and we have come to regard the easily determined magnetic properties as reliable indicators of the activity that may be expected from any given oxide. We long ago[1] expressed the opinion that the relation between biological activity, which is catalytic in nature, and magnetic properties is more than a purely empirical one since both are functions of lattice imperfections and internal strains which are determined by the method of preparation. This opinion gains considerable support from the recent work of Eckell[2] who compared the catalytic activities of strained and unstrained nickel.

The reason for presenting the results of our magnetic studies, which were, in a sense, secondary to our main purpose, is that they seem to have a bearing on the great variability found in the magnetic properties of natural magnetites.[3] We find a correspondingly wide range in the artificial oxides of iron. While our studies do not identify the fundamental elements of the problem, we hope that this paper will be a contribution to its solution.

Classification and Preparation of the Oxides.

The methods of preparation will be indicated only in more general terms. Whenever possible we shall give the reference to the paper in which details may be found. We assign a reference number to each oxide or substance that was studied, which is used later to identify the curves of Figs. 1 to 6 and the data of Table I.

[1] Baudisch, O., and Welo, L. A., Naturwissenschaften, **14**, 1005, 1926.
[2] Eckell, J., Zeit. f. Elektrochem., **39**, 433, 1933.
[3] Wilson, E., and Herroun, E. F., Proc. Phys. Soc. London, **31**, 299, 1919; **33**, 196, 1921; **41**, 99, 1928; Wilson, E., Jl. Inst. Elect. Eng., **59**, 319, 1921.

Magnetites: Direct Preparation. Fig. 1, Nos. 1 to 4.

1. Precipitation from an equimolar solution of $FeSO_4$ and $Fe_2(SO_4)_3$ with NaOH. J. Lefort's Method, Compt. Rend., 34, 488 (1852); L. A. Welo and O. Baudisch, Phil. Mag., [7], 3, 396 (1927). Lefort's method does

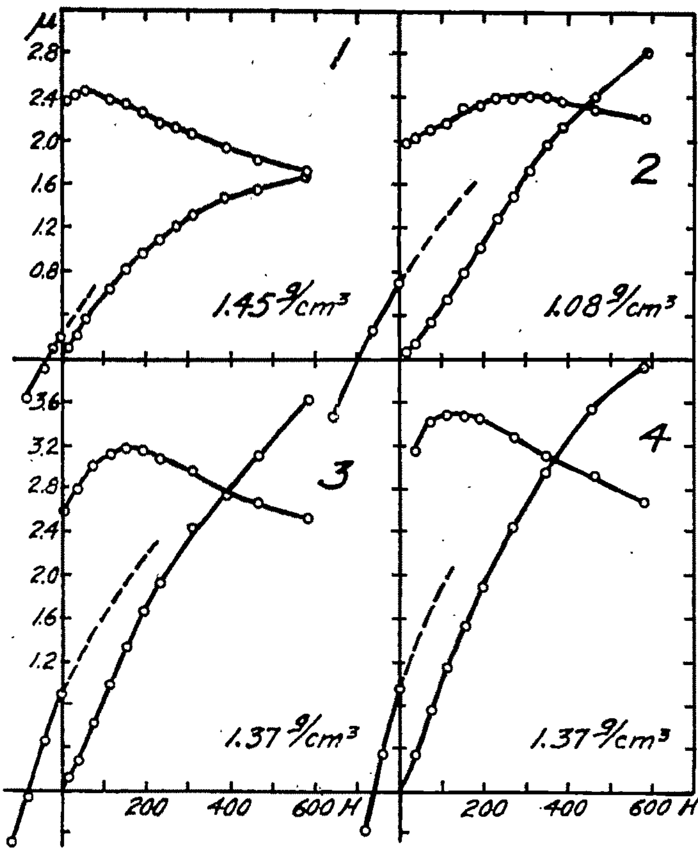

Fig. 1. Magnetites. Direct preparation.

not yield a black oxide as it is always over-oxidized. The FeO content is of the order 17% instead of the theoretical 31% for magnetite, $Fe_3O_4 = FeO.Fe_2O_3$.

2. A black commercial preparation. D.R.P. No. 463773 (1925) and No. 464561 (1926) to Dr. Julius Laux, Uerdingen.

3. This black magnetite was formed by burning iron carbonyl sprayed into a hot chamber with limited supply of air. Preparation is described by A. Mittasch, Zeit. f. angew. Chem., 41, 827 (1928) and D. R. P., 452, 360 (1926). We regard this as the purest sample of magnetite that we have studied and consider it to be a "standard" sample of magnetite.[4]

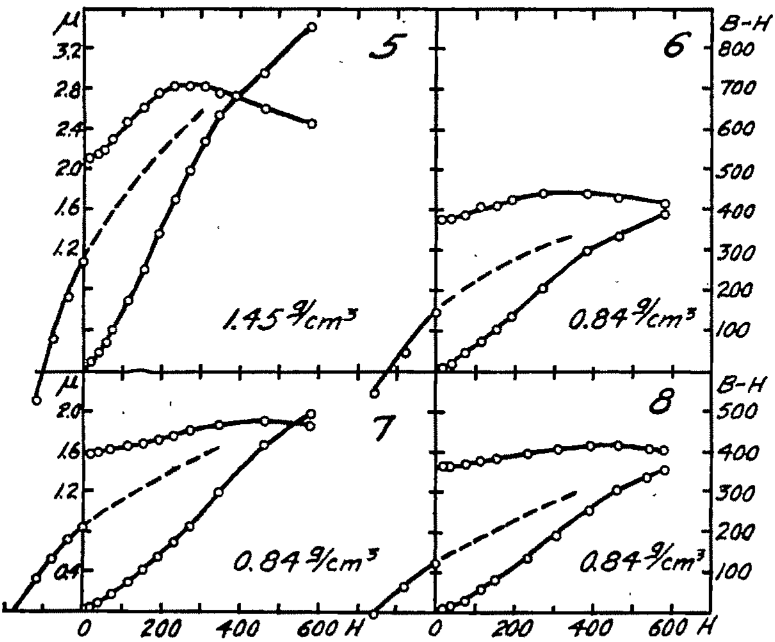

Fig. 2. Magnetites. By reduction of Ferric Oxides.

4. Formed in the same way as No. 3 and subsequently kept in molten sodium acetate at 320° C. for 10 minutes. The hot sodium acetate and the oxide were then poured into water or on an aluminum plate. Either way provides rapid cooling. The oxide was washed until free of acetate and air dried. This is a new way of reducing iron oxides.

Magnetites: By Reduction of Ferric Oxides. Fig. 2, Nos. 5 to 8.

5. Oxide No. 1 was oxidized in oxygen at 200° C. until free of ferrous iron. Then it was reduced as in No. 4.
6. Alpha ferric oxide was made by oxidizing a solution of

[4] We thank Professor H. von Euler of Stockholm for providing us with this magnetite.

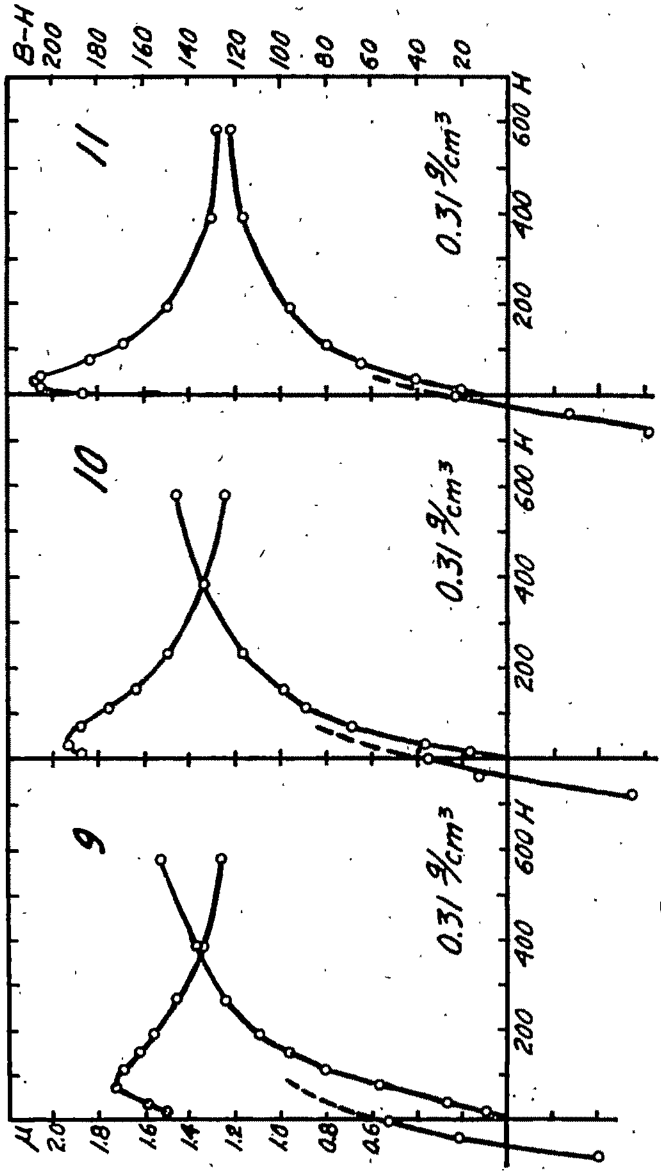

Fig. 3. Ferromagnetic Ferric Oxides (Gamma Oxides). By Dehydration of Gamma Ferric Oxide Hydrates.

ferrous carbonate. This carbonate solution was made by dissolving iron powder from iron carbonyl in carbonated water. The alpha oxide was then reduced to magnetite as in No. 4 except that potassium acetate was used and the temperature was 460° C.

7. Alpha ferric oxide was made by burning iron carbonyl as in No. 3 but with a sufficient supply of air for complete oxidation. The ferric oxide was reduced in sodium acetate as described in No. 4.
8. Prepared in the same way as No. 7.

Ferromagnetic Ferric Oxides: By Dehydration of Gamma Ferric Oxide Hydrates. Fig. 3, Nos. 9 to 11.

9. The preparation of gamma ferric oxide hydrate is described in another paper; L. A. Welo and O. Baudisch, Phil. Mag., in press. Dehydration was carried out by heating, successively, for 5 hours at 180° C., 2 hours at 200° C., 2 hours at 220° C., 2 hours at 240° C., and 2 hours at 260° C. in air.
10. The gamma hydrate was prepared as in No. 9 but NaCl was purposely added to the ferrous chloride to provide an impurity while the crystals were formed. The hydrate was converted to oxide by heating, in air, at 200° C. for 46 hours.
11. Gamma hydrate was made with a solution of FeI_2 instead of $FeCl_2$ and dehydrated at 200° C. for 48 hours.

Ferromagnetic Ferric Oxides: By Oxidation of Magnetites. Fig. 4, Nos. 12 to 15.

12. Lefort's magnetite, No. 1, was oxidized in oxygen at 200° C. until free of ferrous iron.
13. Magnetite No. 1 was oxidized in molten KNO_3 at 395° C. for 10 minutes. The molten nitrate with the oxide were poured on an aluminum plate, washed until free of nitrate, and dried in air.
14. Magnetite No. 2 was oxidized by the method that was used when preparing No. 13.
15. Magnetite No. 7 reoxidized in molten KNO_3 at 360° C. for 10 minutes.

Copper Ferrites. Fig. 5, Nos. 16 and 17.

16. By precipitation of a solution of $FeSO_4$ and $Fe_2(SO_4)_3$ with NaOH in the presence of $CuSO_4$. This ferrite contained 3.9% of copper.
17. The same method was used as in No. 16 but relatively more $CuSO_4$ was present in the solution. The copper content of this ferrite was 9.2%.

Iron Powder from Iron Carbonyl. Fig. 6, Nos. 18 and 19.

18. For method of preparation see A. Mittasch, Zeit. f. angew. Chem. 41, 827 (1928). The carbon content of this sample was stated to be less than 0.001%.
19. Same as No. 18, except that the carbon content was 0.02%.

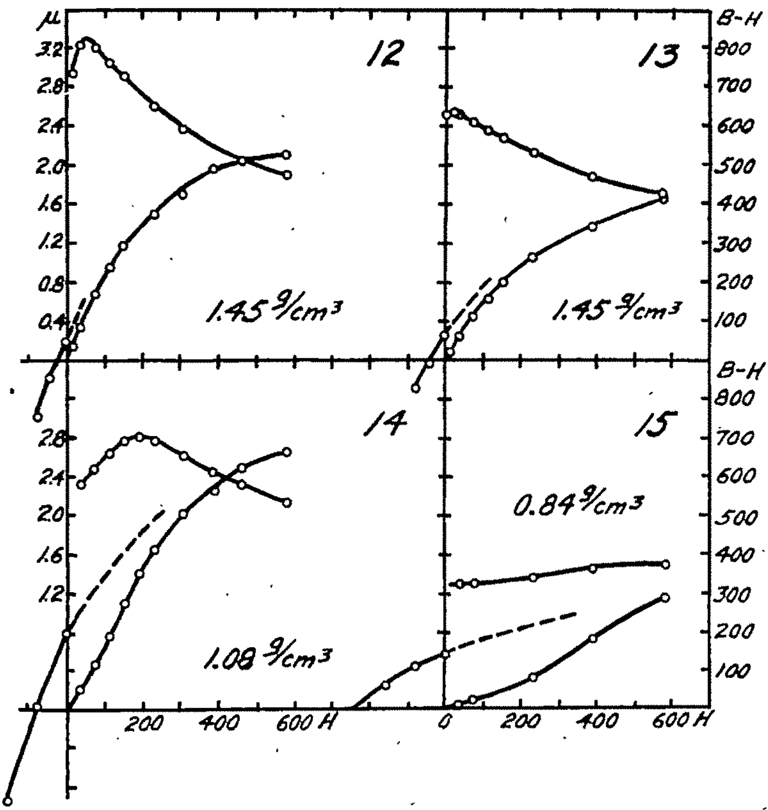

Fig. 4. Ferromagnetic Ferric Oxides (Gamma Oxides) by Oxidation of Magnetites.

Results.

The magnetic data are given in Figs. 1 to 6 and in Table I. The curves were drawn from ballistic data obtained by a method we have already described.[5] For each preparation there is shown a permeability and magnetization curve and a

[5] Welo, L. A., and Baudisch, O., Phil. Mag. [6], 50, 399, 1925; [7], 3, 396, 1927.

portion of the hysteresis loop where it crosses the axes. The remanences and coercive forces are therefore also given from the highest magnetizing field that was used, 582 gausses.

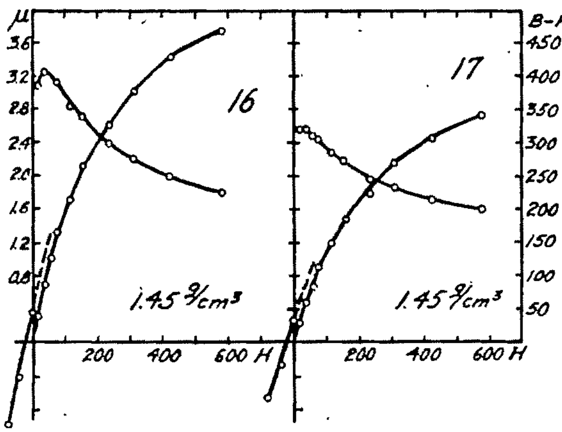

Fig. 5. Copper Ferrites.

Table I contains the specific remanent magnetizations from magnetizing fields of 1790 gausses. The magnetometer method used for these latter measurements is described in another paper.[6]

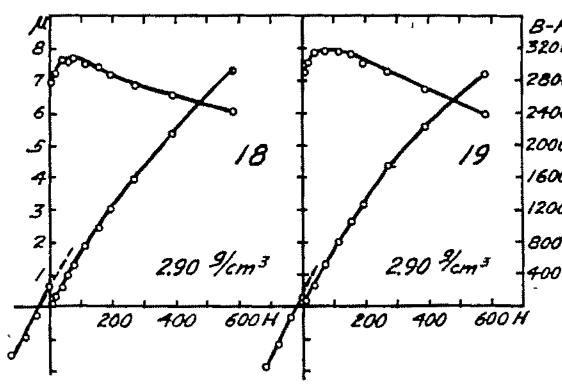

Fig. 6. Iron Powder from Iron Carbonyl.

There was a wide variation in the density of packing. Density of packing could not be accurately controlled and our practice was to adjust the observed values of permeability and

[6] Welo, L. A., and Baudisch, O., Phil. Mag., in press.

magnetization to correspond to some standard packing density, provided that the range of adjustment was not too great. Consequently several standard values are recorded in the figures. Density of packing is not involved in the calculation of the specific remanent magnetizations from the magnetometer measurements. But the values obtained do depend on the packing density so that these densities are included in Table I. The latter values are higher than the values shown in the figures. The material was tamped with a rod while being packed in the magnetometer container. The container used for the ballistic measurements was packed by "jarring." Water determinations were not made so that it was not possible to adjust the permeabilities, magnetizations and the remanences to the water free basis.

Discussion of the Results.

Some conclusions of a general nature can be drawn from these magnetic data.

There are no major differences between the magnetic properties of magnetites and those of the ferromagnetic ferric oxides.

The effect of impurities is a minor one as may be seen by an intercomparison between several sets of curves. Oxides No. 9 and No. 11 were pure while No. 10 was purposely precipitated in NaCl solution. The greater hardness in No. 9 is due to the higher temperature used while dehydrating the gamma ferric oxide hydrate from which it was formed. Magnetite No. 4 has the same general magnetic characteristics as the standard sample No. 3 in spite of the fact that it has been heated in molten sodium acetate. A similar conclusion as to the minor rôle of impurities is drawn from a comparison of No. 9 with No. 1. No. 9 is a pure material while No. 1 contains many impurities.[7]

There is consistent evidence among these data that a high temperature at some time during formation yields a material that is magnetically hard; except when a material that is already magnetite is oxidized to ferromagnetic ferric oxide. No. 3 was formed at an elevated temperature and No. 5 and No. 6 were heated during reduction with an alkali acetate. The hardest oxides of all were those which had been heated twice during the course of preparation; first, during the burning of

[7] For a complete analysis see Wolf, P. M., and Zeglin, H., Deut. Med. Wochenschrift, No. 24, 1929.

iron carbonyl to form alpha ferric oxide and, subsequently, during reduction with sodium acetate. Examples of this double heating are Nos. 7, 8 and 15. Of these, No. 15 had been heated three times, the last time during oxidation in molten KNO_3. This oxide had by far the highest coercive force that was observed during this study, 240 gausses.

The effect of oxidizing magnetite, either in air at 200° C. or in molten KNO_3, is to soften the material. Compare No. 12 and especially No. 13 with No. 1 and also No. 14 with No. 2. This behavior has been noted by us before.[8] Comparison of No. 15 with No. 7 suggests, however, that this rule is not invariable.

The copper ferrites are extremely soft. We believe that their softness has the same cause as softness in ferromagnetic ferric oxides as compared with the magnetites from which they

TABLE I.

Specific Remanent Magnetizations in Ferromagnetic Iron Oxides, Copper Ferrites and Iron Powder. From H = 1790 Gausses.

Number Reference	Material Class of	Density of g./cm. 3 Packing	e.m.u. σ_r
1	Fe_3O_4	1.51	1.97
2	"	1.67	14.5
3	"	2.24	15.8
4	"	...	...
5	"	1.58	16.2
6	"	0.95	12.8
7	"	1.15	17.0
8	"	...	...
9	Fe_2O_3	...	...
10	"	0.69	7.37
11	"	0.67	3.66
12	"	1.69	1.80
13	"	1.51	1.95
14	"	1.77	15.2
15	"	1.57	15.5
16	$CuO.Fe_2O_3$	1.62	0.68
17	"	1.59	0.50
18	Fe	3.52	2.75
19	"	3.04	2.73

were made by oxidation. The lattice in ferromagnetic ferric oxide is crowded and strained owing to the presence of more oxygen than corresponds to the magnetite structure which is retained. In the case of the copper ferrites, the lattice is

[8] Welo, L. A., and Baudisch, O., Phil. Mag. [6], 50, 399, 1925; [7], 3, 396, 1927.

strained because the copper ions are larger than the ferrous ions. It may be noted that of the two ferrites, the one containing the most copper is the softer. These ferrites are cubic in structure.

The iron powder is hard, for iron, as it was expected to be because of its powdered form. We notice no effect of the presence of carbon within the small range involved here, 0.001 to 0.02 per cent.

The remanences in either magnetite or ferromagnetic ferric oxide group themselves around three main values according to the data of Table I. Nos. 1, 12 and 13 form a group with specific remanent magnetizations, σ_r, of about 1.90. Nos. 12 and 13 were derived from No. 1 by oxidation. The oxides derived by dehydration of gamma ferric oxide hydrate, Nos. 10 and 11, form another group with intermediate values. A value, $\sigma_r \doteq 11.0$, was reached in other work on ferromagnetic ferric oxide derived in this way when it was heated for a much longer time or at higher temperatures. The rest of the magnetites or the ferromagnetic ferric oxides form a group with specific remanent magnetizations of from 14.5 to 17. No. 6 with $\sigma_r = 12.8$ probably would have fallen within this group if it could have been more densely packed.

If it be granted that the magnetic properties of magnetite and of ferromagnetic ferric oxide are mainly determined by previous history as to temperature it remains to consider the physical changes that may occur at high temperatures. The principal ones are: growth of crystals and coalescence of particles, elimination of lattice irregularities and removal of strains. To identify changes in magnetic properties with any one of these has been difficult because they may all occur on heating, and our point of view has changed from time to time as new experimental facts have appeared.

In a previous paper[9] we showed that Lefort's magnetite, No. 1 of this paper, gave diffuse lines in the X-ray diffraction pattern, proving that the crystals were small. The other magnetites described in that paper were magnetically hard and gave the sharp lines characteristic of large and well formed crystals. However, we could not conclude that magnetic softness is associated with small crystal size. We found that Lefort's magnetite, when it was annealed at 1000° C., became hard with properties approaching those of Nos. 2 and 5 of this paper. There was evidence that the crystals had not

[9] Welo, L. A., and Baudisch, O., Phil. Mag. [7], 3, 396, 1927.

grown appreciably during the annealing so we concluded that the change from a soft to a hard condition was due to either perfection of the lattice, or removal of strains, or both, and that magnetic properties are independent of crystal size.

The reader is referred to another paper[10] for a description of our work on ferromagnetic ferric oxide derived by dehydration of gamma ferric oxide hydrate, and on ferromagnetic ferric oxide particles of colloidal dimensions. We have been led anew to the conclusion that magnetic hardness in this class of material is a function of crystal or particle size, at least within the range in which they are very small.

[10] Welo, L. A., and Baudisch, O., Phil. Mag. (In press).

YALE UNIVERSITY,
NEW HAVEN, CONN.

SCIENTIFIC INTELLIGENCE.

Chemistry.

The New Hydrogen. (Nature, March 31, 1934. Pp. 481-484.)—In this article Lord Rutherford gives a résumé of the discovery and investigation of the heavy hydrogen isotope. For well over one hundred years the chemist had been so confident of the definite composition of pure water that the units of mass now in general scientific use were originally referred to the mass of a certain volume of water. The discovery some years ago of isotopes of oxygen of mass 17 and 18 did little to disturb this confidence, for although these isotopes meant that ordinary water would contain some molecules of mass 19 and 20 instead of 18, it appeared unlikely that the proportions of such isotopes could be sensibly varied, so their presence made no practical difference. But the last two years brought forth the revolutionary idea that hydrogen of mass 2 was always present along with ordinary hydrogen—perhaps in the proportion of 1 : 6000—no matter what means of preparation were used. In one respect, Rutherford points out, the discovery of this isotope was similar to the discovery of the element argon, both being due to the recognition of small differences in accurate density measurements. In an effort to determine the abundance of the isotopes of oxygen, a discrepancy of one part in 5000 was found between the masses of hydrogen and oxygen measured by Aston's positive ray method and the ratio obtained by chemical means. Since this was outside the experimental error, it was explained by the suggestion that a double-weight hydrogen isotope was present in very small amount. Direct experimental evidence was then sought from spectrum analysis. Both isotopes should exhibit very similar spectra, but since the vibration of the single free electron in each type of atom depends to some degree on the mass of the nucleus, the position of the spectrum lines of the heavier isotope should be shifted toward the red end, and if a very little of this isotope were present in a sample of normal hydrogen, faint satellite lines should accompany the normal lines. Such displacement can be calculated, and was known to be very slight, but such an extra line was finally detected in the right place by Urey, Brickwedde, and Murphy. Their measurements indicated a concentration of the heavy isotope of the order of one part in 5000.

Since this isotope has a mass double that of the ordinary hydrogen, the physical properties are sufficiently different so that the concentration of the isotope could be changed. Thus, for the first time, we have been able to isolate an isotope in essentially pure state. Fractional distillation of liquid hydrogen or, better, the

electrolysis of water, since the lighter hydrogen atoms are released faster than the heavy ones, has been successfully employed as a means of concentrating the new isotope. Although any method of isolation is tedious, a sample of the gas has been prepared which is spectroscopically free from the light isotope, and "heavy water," "heavy ammonia" and certain other compounds have been prepared which are very nearly free from ordinary hydrogen. Samples of this water have a density about 10% greater than ordinary water and also differ notably in boiling and freezing points and in other respects. It is interesting to note that such water contains nearly 9% more hydrogen by weight than the water we drink although the atomic ratio of hydrogen to oxygen is identical. Only small amounts of such compounds have been prepared and although much research has been started concerning the effect of heavy water on life processes, no general conclusions can be drawn yet. One worker has found that when hydrogen and deuterium—as the heavy isotope is usually called—are mixed over a nickel catalyst, new molecules are formed each of which contains one light and one heavy hydrogen atom. This rearrangement is suggested as a means of determining the efficiency of different catalysts, and is the only practical use of deuterium at present.

Deuterium has received the greatest attention from its use (as the ion) as a projectile in atomic bombardment for causing transmutation of certain elements. In this respect it is ten times as effective as the proton from ordinary hydrogen. Most interesting results were obtained when ammonium salts in which most of the normal hydrogen was replaced by deuterium were bombarded with deutons from the heavy hydrogen. In such cases a great number of enormously fast-moving protons were emitted with apparently more energy than had been put into the system. The suggested explanation is that two deuton nuclei first unite to form a helium ion. But this helium ion contains too much energy to be stable and promptly explodes forming a normal hydrogen atom and a hydrogen particle of mass 3. The existence of such a third isotope had been predicted from abstract calculations, but this was the first direct evidence for its existence. No sensible amount of this newest isotope has been isolated, and its existence is not yet universally admitted. E. B. KELSEY.

Geology and Mineralogy.

Metamorphism: A Study of the Transformations of Rock-Masses; by Alfred Harker. Pp. 360; 185 figs. London, 1932 (Methuen & Co.); New York, 1933 (E. P. Dutton & Co., $5.90).—This brilliant exposition of metamorphic geology is a keen pleasure to read. The book moreover is illustrated with extraordinary effectiveness by a large number of pen-and-ink drawings

of metamorphic rocks as seen under the microscope. They illustrate a vast range of metamorphic phenomena and manifestly embody an immense amount of labor. The examples and illustrations have avowedly been taken almost wholly from British sources.

The book consists of two parts. Part I treats of "Thermal Metamorphism," *i.e.*, contact, or igneous, metamorphism; and Part II deals with "Dynamic and Regional Metamorphism." On the theoretical side the book is less felicitous. To use pressure as meaning hydrostatic pressure, and to define stress as comprising "both pressure and shearing stress," when in reality stress means force per unit area, does not help to advance geology as a science. The term regional metamorphism, it need hardly be said, is now regarded by active students of metamorphism as of hardly more than historical interest. No cognizance is taken of the epochal work of Sander and Schmidt, which is revolutionizing the currently accepted tenets of metamorphic geology.

The great body of facts illustrative of the manifold variety of metamorphic rocks is extremely well presented and made available in systematic form. On these counts alone the book is indispensable to all interested in metamorphic geology.

ADOLPH KNOPF.

The Silurian Faunas of North Greenland. I. The Fauna of the Cape Schuchert Formation; by CHR. POULSEN. Meddel. om Grönland, Bd. 72, No. 1, 46 pp., 3 pls., 5 text figs., 1934.—The Silurian of northernmost Greenland, as revealed by Lauge Koch, has four formations with a thickness ranging between 5000 and 6500 feet. It is the fauna of the oldest formation, 325-650 feet thick, that is here described, consisting of 42 species, of which 28 are specifically named and 20 are new. There are two new genera, *Pseudoproetus* and *Ceratocypris*. Of corals there are 2, of graptolites 5, of brachiopods 12, of trilobites 20, and of ostracods 2. Of stratigraphic interest is the correlation of the Offley Island limestone, which in places reaches a thickness of 2600 feet, with the thin *Monograptus sedgwicki* shale zone of Europe. C. S.

Further Contributions to the Devonian Stratigraphy of East Greenland. I. Results From the Summer Expedition 1932; by G. SÄVE-SÖDERBERGH. Meddel. om Grönland, Bd. 96, No. 1, pp. 1-40, 3 pls., 15 text figs., 1933.—This is a report of progress describing in detail the stratigraphy of the various exposures of Upper Devonian formations of continental origin, which yield fishes (*Remigolepis*, arthrodires, etc.) and stegocephalians. The thickness of the strata ranges between 1200 and 1600 feet, with the base and top not yet fixed. C. S.

Untersuchungen über die Verbreitung, Lagerungsverhältnisse und Fauna des Oberen Jura von Ostgrönland; by HANS FREBOLD.

Meddel. om Grönland, Bd. **94**, No. 1, pp. 1-81, 3 pls., 14 text figs., 1933.—Frebold here brings together all that is now known of the Upper Jurassic of East Greenland, which has a described fauna of about 45 species (essentially bivalves and ammonites), 10 of them specifically named. The Jurassic transgression began at some time between the Callovian and the Oxfordian, and continued into early Kimmeridgian time, when the sea retreated from East Greenland, to return in the early Cretaceous. The tectonic and paleogeographic aspects are discussed, and the interesting conclusion reached that an island borderland once existed east of the Jurassic deposits and west of the old Scandic sea. C. S.

The Dermal Bones of the Head and the Lateral Line System in Osteolepis macrolepidotus Ag., with Remarks on the Terminology of the Lateral Line System and on the Dermal Bones of Certain Other Crossopterygians; by G. SÄVE-SÖDERBERGH. Nova Acta Reg. Soc. Sci. Upsaliensis, Ser. IV, Vol. **9**, No. 2, pp. 130, 16 pls., 22 text figs., 1933.—This thorough work on late Middle Devonian (Orcadian) fishes from Scotland has the earmarks of Scandinavia and Kiaer and Stensiö, the source from which the most detailed morphology of early Paleozoic vertebrates now emanates. The present notice is intended only to direct attention to the work and give a few of its conclusions: The early crossopterygians and tetrapods are more nearly related than is usually believed, and the primitive dipnoans have close affinities with these two groups. The fins of crossopterygians and dipnoans "have their most important and characteristic feature in common with the legs of the Tetrapods." The three stocks are here grouped together under the new term *Choanata*, proposed to include animals with internal nostrils. The urodeles are probably of different origin from the stegocephalians, and are more closely connected with the dipnoans, whereas the stegocephalians are "clearly more nearly related to the crossopterygians," and the latter "are possibly also polyphyletic." C. S.

Weitere Beiträge zur Kenntniss des Oberen Paläozoikums Ostgrönlands; by HANS FREBOLD. Meddel. om Grönland, Bd. **84**, No. 7, pp. 1-61, 6 pls., 1 text fig., 1933.—In the Lower Triassic conglomerates of East Greenland occur boulders containing Upper Permian fossils, which represent three different horizons. None of the twenty species, of which ten are specifically determined, occurs in the known Permian formations of Greenland, and the inference is that the strata represented only by the fossils in the boulders occur farther west and probably in the area of Cape Stosch. It is now all the clearer that the Permian fauna of East Greenland is not that of Russia, but that of Germany and England. C. S.

Monographie der Obersilurischen Graptoliten aus der Familie Cyrtograptidae; by BEDRICH BOUCEK. Práce Geol.-Pal. ústavu Karlovy Univ. v Praze, 1933, No. 1, pp. 84, 7 pls., 19 text figs., 1933.—This detailed and abundantly illustrated monograph on the Silurian monograptids describes the following genera: *Cyrtograptus*, 19 species in 4 groups; 16 occur in Bohemia, and 2 of them are new. *Barrandeograptus*, 3 species, 2 occurring in Bohemia, and 1 new. *Diversograptus*, 4 species, 2 in Bohemia and 1 new. *Linograptus*, 2 species. It is a praiseworthy contribution to our knowledge of the graptolites. C. S.

Les Ressources Minérales de la France d'outre-Mer: Part I, Le Charbon. Pp. 245, 33 figs. Publicat. du Bureau d'Études Géologiques et Minières Coloniales. Paris.—In "La Géologie et les Mines de la France d'outre-Mer" (this Journal, vol. 25, p. 268, 1933) the general features were outlined of the geology and mineral resources of the French colonial empire. In the present and succeeding volumes it is proposed to give detailed accounts of the principal resources, one by one. In this volume the economic geology of the coal deposits of North Africa, Indo-China, and Madagascar are presented. The bibliographies for the several fields show that a surprising amount of work has already been done in studying the coal resources.

Part II, Le Fer, et al. Pp. 436, 59 figs. Paris, 1934.—In this, the second volume of the project described above, various authorities have presented the economic geology of the deposits of iron, manganese, chromium, nickel, tin, tungsten, graphite, beryllium, molybdenum, cobalt, titanium, and vanadium. The accounts give as a rule the geologic mode of occurrence of the deposits, with more or less extended treatment of the metallurgy, industrial uses, and markets. A. K.

Hintze's Handbuch der Mineralogie.—Mineralogists will be much interested to learn that the Mineralogy begun by Professor Carl Hintze of Breslau in 1889, forty-five years ago,* has now been completed. Hintze carried the work on through 19 Lieferungen, and upon his death, Professor Gottlob Linck of Jena took up the task. With the assistance of many colleagues, he has now carried it on to completion. The exhaustive thoroughness of this monumental and invaluable work is shown by the following facts:

Vol. I appears in 4 parts: Part 1, Elements and Sulphides, completed in 1904, contains 1208 pages; (price RM. 38). Part 2, Oxides and Haloids in 1915, pages 1209-2674 (RM. 46). Part 3, Nitrates to Uranates in 1930, pages 2677-4565 (RM. 160). Part 4, Borates, etc., in 1933, pages 1-1454 (RM. 104). Volume II. Silicates and Titanates in 1897, pages 1841 (RM. 58). The whole work, therefore, reaches the remarkable total of nearly 8000 pages.

* See this Journal, III, vol. 38, p. 251, 1889.

The publishers are Messrs. Walter de Gruyter & Co., Berlin W. 10, and Leipzig. The various parts may be obtained from them at the prices named, or, if bound in half leather, at an increase for each part of 10 to 16 RM.

The Mineral Industries of Canada, 1933. Compiled by A. H. A. Robinson, with the coöperation of the Mines Branch, John McLeish, Director. Pp. 116; 34 pls., map of Canada (one inch = 100 miles) in pocket. Ottawa, 1934 (25 cents).—This valuable volume gives first a concise but interesting summary of the mineral production in Canada from 1886 to 1932. During that time the total value varied widely year by year; thus in 1886 it was \$10,221,253, while it reached a maximum of \$310,800,246 in 1929. Another table presents the values (1907-1932) for the three classes: (1) Metallics, (2) Non-metallics (with fuels), (3) clay and other structural materials. The increase for the period named is greatest in the first group. Still further to be mentioned here are the separate tables giving the values for each of the nine provinces; also others with the quantities and values of the individual products as contrasted in 1931 and 1932.

On the following pages (9-88), each of the individual products, arranged alphabetically, is discussed in detail, with 24 excellent plates. The accompanying map, 16 × 36 inches (100 miles to one inch), gives the entire area of the Dominion. Here the individual localities are distinctly marked with token-signs for each of the products, nearly sixty in all.

Minerals Yearbook, 1932-33; O. E. Kiesling, Chief Economist. Pp. xiii, 819; 90 figs. Washington, D. C. Bureau of Mines, Scott Turner, Director. \$1.25 cloth from the Government Printing Office. Free to reference libraries and universities. —This new publication takes the place of earlier volumes including the "Mineral Resources of the United States." Briefly stated, it presents in full detail a summary of each of the individual years 1928 to 1932.

The opening chapter gives an interesting account by Dr. Turner of the status of the Mineral Industries during the years 1921 to 1932. From 1925 to 1929 the world's mineral output developed to a maximum of about 70 billion dollars, or an annual average of 14 billion. In the years following 1929, the amount diminished as follows: In 1930 to 12.5 billions; in 1931 to 9 billions; in 1932 to 7 billions, or half that of 1929. This decrease is explained as due both to reduction in operation and lower prices.

In Part II (pp. 11 to 819) the individual metals and non-metals are discussed in detail by many authors and the production and value of each given. Graphic figures add clearness to the facts presented.

Miscellaneous Scientific Intelligence.

Handbuch der biologischen Arbeits methoden; edited by Dr. Emil Abderhaldèn. Berlin (Urban & Schwarzenberg).—Lieferung 365, Abt. IV. Teil 13, Heft 4. Contains two papers on practical physical and chemical methods for research in quantitative assimilation:—1. *The technique of pharmacological research*; by Otto Graf-Dortmund. Pp. 289-376; 21 figs.—2. *A new universal apparatus for microanalysis*; by Ernst Tschopp. Pp. 377-434; 3 figs.

Lieferung 401, Abt. IX. Teil 2, 2 Hälfte, Heft 5. Methoden sur Erforschung der Leistungen des tierischen Organismus. Contains these three papers on the study of fresh-water biology:

1. *The limnologic Laboratory in Aneboda, Sweden*; by Einar Nauman. Pp. 1619-1646; 21 figs.—Defines the purpose and scope of this laboratory; it is small, but, situated in southern Sweden, is favorable for fresh-water biological research. Established in 1907, it is now (since 1929) united with the University in Lund.

2. *The study of assimilation in aquatic bacteria*; by Adolf Seiser. Pp. 1647-1728, 8 figs.—Treats the organic and inorganic sources of energy and nitrogen of aquatic bacteria and describes methods for their discovery and measurement. Biproducts of the various chemical processes are discussed. References to pertinent literature are included.

3. *The field study of Limnoplankton*; by W. M. Rylov. Pp. 1729-1774; 35 figs.—Describes and illustrates general methods of collecting plankton of ponds and lakes; the structure and use of devices for qualitative and quantitative work in the field; and the equipping of expeditions for such work. The procedure for studying on the spot the plankton taken in the nets is discussed; even the centrifuge may be used in the field. Fifty-two related papers are appended.

Lieferung 404, Abt. IX, Teil 5, Heft 6. *Methoden der Erforschung der Leistungen des Tierischen Organismus.* Methods of salt-water biology.—*Bacteriology of the Sea*; by Wilhelm Benecke. Pp. 717-854, 1933.—A valuable paper, not illustrated, but supported by a compact bibliography.

The table of contents and author index for Abt. IX, Teil 5, are given in this issue.

Lieferung 395, Abt. IX, Teil 6, Heft 2, 1932. *The Rearing of Marine fishes for scientific and practical Purposes*; by Helmut Hertling. Pp. 195-366; 84 figs.—This is a comprehensive paper illustrated with photographs and drawings of fishes; also showing the apparatus for collecting and culturing.

LIEFERUNG 410, Abt. IX, Teil 6, Heft 3, 1933.—This third number on methods in salt-water biology contains two articles: 1. *The taking and study of mud-samples and the culture of their living microfauna*; by CARL J. CORI, pp. 367-376. Outlines of material and methods, with reference to other works, are included here.

2. *The taking and study of sea-bottom samples*; by OTTO PRATJE. Pp. 376-542; 64 figs.—A useful description of apparatus, methods, locating and recording of stations, kinds and use of sounding apparatus; also the sorting and measurement of the organic and inorganic content of the samples. A full bibliography is added. S. C. B.

An Introductory Course in Science for Colleges; II, *Man and the Nature of His Biological World*; by FRANK COVERT JEAN, EZRA CLARENCE HARRAH, and FRED LOUIS HERMAN, with the editorial collaboration of SAMUEL RALPH POWERS. Pp. x, 589; 234 figs. Boston, New York, et als., 1934 (Ginn and Co., $2.40).—This book has been prepared in response to the belief of many leaders in education that specialized courses in the various sciences have proved less satisfactory for the average college student than a more broadly generalized treatment of a group of sciences. To this end the authors have covered the entire field of biological sciences, both theoretical and practical, leading from a discussion of the properties of the living substance, through all the life processes of organisms to man's cultural development up to the time of his ultimate arrival at the machine age. The subject is clearly presented, with a minimum of technical terms, all of which are to be found in the included glossary. The illustrations are adequate. It is doubtful if any other book presents in equal space so many of the things about man and his biological surroundings that are really worth knowing. W. R. C.

Handbook of Technical Instruction for Wireless Telegraphists; by H. M. DOWSETT. Fifth Edition revised and enlarged. Pp. 566; 525 diagrams and illustrations. London, 1934 (Iliffe & Sons, 15/-net).—This book was written primarily for wireless operators, especially those in England desiring to qualify for the Postmaster General's Certificate of Proficiency. The definitions are particularly good as they give a clear understanding of the exact significance of the various terms used. The first half of the book gives a very satisfactory presentation of the general elementary principles of electrical engineering suitable for a beginner. The remainder, which is descriptive rather than analytical, is devoted to radio circuits and apparatus many of which are of historical interest only. A detailed analysis of some of the more

important circuits would have added greatly to the value of the book. For the amateur who is interested in experimenting with all types of circuits a wide range of selection is provided.

H. M. TURNER.

Public Museum of the City of Milwaukee, S. A. BARRETT, Editor; IRA EDWARDS, Assistant Editor.—The following publications have been recently received.

BULLETINS. Vol. VII, No. 2. The Tamarack Bogs of the driftless Area of Wisconsin; by HENRY P. HANSEN. Pp. 231-304, pls. 39-44, figs. 1-3, maps 1-27.—Vol. VII, No. 3. An Ecological comparison of two Wisconsin peat bogs; by JOSEPH W. RHODES. Pp. 305-362, figs. 4-7, maps 28-48.

Vol. XV. Pomo Myths; by S. A. BARRETT. Pp. 608, Nov. 6, 1933.

VOL. XVI, No. 1. The excavation of Ross Mound Group I; by PHILLEO NASH. Pp. 1-46, pls. 1-9, figs. 1-8, map 1, Dec. 20.—No. 2. The Red Cedar Variant of the Wisconsin Hopewell Culture; by L. R. COOPER. Pp. 47-108, pls. 10-17, figs. 9-12, map 2, Dec. 20, 1933.

Title Page and Index of Vol. II, Nos. 1-4, pp. 377-403. Also of Vol. X, Nos. 1-5, pp. 553-561.

Obituaries.

Dr. Nathaniel Lord Britton, director-in-chief of the New York Botanical Garden for thirty-three years, died on June 25 in his seventy-fifth year. A botanist of the first rank, his publications were numerous and important. He served on the Geological Surveys of New Jersey and of the United States, and was professor of botany in Columbia University.

Madame Marie Curie, who shared with her husband, Pierre Curie (d. 1896), in the discovery of radium, died on July 4 at the age of sixty-six. Her keenness and success in investigation place her at the head of all woman scientists.

Rev. Guiseppie Gianfrancheschi, the distinguished scientist of the Vatican and Director of the Vatican radio station, died on July 9 at the age of fifty-nine.

Dr. Jacob Sederholm, Director of the Geological Survey Commission of Finland and one of the leading European geologists, died on June 27 at the age of seventy-one.

Dr. J. R. van der Stok, director from 1899 to 1923 of the section of oceanography and maritime meteorology at the Bill Meteorological Institute near Utrecht, died recently at the age of eighty-three.

Dr. Thomas Huston Macbride, professor of botany at the Iowa State University 1884 to 1914, and president emeritus since 1916, died on March 27 at the age of eighty-six.

Dr. John Menton Aldrich, the entomologist, curator of insects at the U. S. National Museum since 1919, died on May 27 at the age of sixty-eight.

Dr. Elizabeth Shelow, of the research laboratory of the University of Cincinnati, died on June 26. Her work in connection with vitamins, especially vitamin D, was of especial importance.

Dr. Harriet Williams Bigelow, professor of astronomy in Smith College, died recently at Soerabaya, Java, at the age of sixty-four.

Dr. Edward Martin Shepard at Springfield, Missouri, professor of biology and geology at Drury College, died on April 28, at the age of eighty.

PUBLICATIONS RECENTLY RECEIVED.

The Crystalline State, edited by Sir W. H. Bragg and W. L. Bragg. Volume I. A General Survey, by W. L. Bragg. New York, 1934 (The Macmillan Co., $5.50).

An Introductory Course in Science for Colleges. Frank C. Jean, Ezra C. Harrah and Fred L. Herman. I. Man and the Nature of His Physical Universe. Price $2.20. II. Man and the Nature of His Biological World. Price $2.40. Boston, 1934 (Ginn & Company).

Earth Radio and the Stars; Harlan T. Stetson. New York, 1934 (Whittlesey House, McGraw Hill Book Co., $3.00).

Tertiary Faunas. A Text-book for Oil-field Paleontologists and Students of Geology. Vol. II. The Sequence of Tertiary Faunas; by A. Morley Davies. London, 1934 (Thomas Murby, 15/— net).

Carte Geologique de l'Angola. Notice Explicative par F. Mouta et H. O'Donnell. 1933 (Ministerio das Colonias, Republica Portuguesa).

The Myxomycetes; by Thomas H. Macbride and G. W. Martin. New York, 1934 (Macmillan Co., $6.00).

Applied Acoustics; by Harry F. Olson and Frank Massa. Philadelphia, 1934 (P. Blakiston's Son & Co., $4.50 Fabrikoid).

The Endless Quest of 3,000 Years of Science; by F. W. Westaway. London and Glasgow, 1934 (Blackie and Son).

The Reaction between Hydrogen and Oxygen; by C. N. Hinshelwood and A. T. Williamson. Oxford and New York, 1934 (Oxford University Press, $3.25).

Biologie Der Fortpflanzung Im Tierreiche; von U. Gerhardt. Berlin, 1934 (Julius Springer, bound RM. 4.80).

Zur Erforschung des Weltalls; von Grotrian and Kopff. Berlin, 1934 (Julius Springer, RM. 18; bound 19.80).

The Human Body; by H. Newell Martin. Twelfth Edition, revised by Ernest G. Martin. New York, 1934 (Henry Holt and Co., $4.00).

AMERICAN JOURNAL OF SCIENCE

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A SALT-MARSH STUDY.

J. BROOKES KNIGHT.

ABSTRACT.

The study of a salt marsh on the shore of Long Island Sound at Killam's Point near New Haven, Connecticut, revealed a section preserving the hitherto unrecorded early stages of a New England salt marsh developed in accordance with Shaler's classic theory, coupled with later stages developed in accordance with the theory first proposed by Mudge and later reproposed and elaborated by Davis. Since the initial stages of salt marshes of the New England type are so rarely preserved, a detailed description is given of the marsh and its setting. The fauna found fossil within the marsh is discussed briefly and is recorded in an appendix. The bearing of the sequence of deposits shown in the section, of the fossil fauna, and of the local setting on the history of the marsh, is considered.

Certain aspects of the origin of coastal marshes of the New England type are briefly discussed.

A striking feature of the rocky, exposed shore of Long Island Sound for several miles east of New Haven, Connecticut, is the common occurrence of patches of salt marsh in the more sheltered coves and even on the shoreward side of rocky islands several hundred yards from the shore. The island marshes, and some of those on the mainland, stand with vertical faces of peat, unprotected by beaches. Both island and shore marshes are being rapidly destroyed by waves. The marshes manifestly could not have established themselves in the relatively exposed positions where they are now found and where they are even unable to maintain themselves, unless under conditions very different from those now prevailing locally. It is the purpose of this paper to describe an example of such a residual salt marsh in its local setting and to inquire into its history and its bearing on theories of the origin and growth of salt marshes of the New England type.

THEORIES OF ORIGIN OF NEW ENGLAND SALT MARSHES.

In a short paper, little space can be devoted to preliminary discussion of the theories of the origin of salt marshes of the New England type. And yet to make much of what is to follow intelligible to the reader who has given little thought to

salt marshes or is unfamiliar with the literature dealing with them a few words seem necessary. For a fuller discussion of the two rival theories one may consult Johnson's invaluable book on the "New England Arcadian Shoreline" (1, chap. 16) where an excellent bibliography of original sources may also be found.

Shaler's theory was seemingly based on observations of surface characters of the marshes. It postulates the silting up of quiet and protected bodies of water to a little above the level of low tide, the process being assisted at certain levels by eel grass, *Zostera marina*. Over the mud-flats so produced the grasses of the salt marsh proper were thought to advance with the formation of a stratum of peat somewhat less in thickness than the mean range of the tides.

The Mudge-Davis theory was arrived at through a study of salt-marsh sections and of the ecology of the salt-marsh grasses. It was found that the surfaces of the marshes at or close to high tide level are occupied by an association of grasses that are closely limited in their vertical range to within a few inches of high-tide level. This association of high-tide grasses is known from the name of one of its principal constituents as the *Spartina patens* association. Ranging from a few inches below high-tide level and down to a little below half-tide grows the coarse salt thatch, *Spartina stricta* (=*Spartina glabra* of authors). Below the zone of *Spartina stricta* no peat-forming vegetation grows, though eel grass is abundant below low tide level. First Mudge in a section of a salt marsh at Lynn, Massachusetts; and then Davis in many sections of New England salt marshes found the marshes to be made up principally of silty peat of the high-tide grasses, the *Spartina patens* association, to depths often ten or twenty feet below the present low-tide level. At the bottom of the peat mass was found in many marshes fresh-water peat and stumps of trees in place. Peat formed from *Spartina stricta* was only found locally and as a newer constituent of the marshes:

These findings led Davis in 1911 to reject Shaler's theory, then almost universally accepted, and to arrive independently at the long-neglected conclusions reached earlier by Mudge, that the marshes were formed through the accumulation of peat of the *Spartina patens* association growing at high-tide level, constantly increasing in thickness and advancing over the land through a long-maintained relative rise of sea level at a rate commensurate with the formation of the peat.

Johnson (1, Chap. 16) recognized that the theory advanced by Mudge and by Davis to account for salt marshes of the New England type did meet the facts as observed in the field by both Davis and himself through the medium of many samples taken from beneath the surfaces of many marshes by means of an ingenious sampler devised by Davis. He also rightly concurs with Davis that Shaler's classical theory fails to meet the conditions revealed by the Davis Sampling device. Nevertheless, he recognizes that Shaler's theory may account for the beginnings of salt marshes at depths not now ordinarily accessible to observation or in localities where the earlier stages have been destroyed by the waves. Thus he writes, "the initial stage of marsh formation, showing the succession of beds figured by Shaler, would be preserved, if at all, at the very bottom of the seaward portion of the marsh" (1, p. 528). And again, he writes (1, p. 521), "Marsh sections showing the theoretical sequence of deposits described by Shaler do exist, however, but they seem clearly to represent local departures from the normal sequence of marsh development, due to recent regeneration of our marshes from which the original deposit had been removed, or to the filling of new areas not previously occupied."

As Johnson points out, "the initial stages of marsh formation . . . . would be preserved, if at all, at the very bottom of the seaward portion of the marsh" (loc. cit.), and hence these stages are rarely found. Indeed, they are found so rarely that Davis reports no example in the numerous sections taken by him, and in his writings takes no account of them whatever. Also, while Johnson notes that Shaler marshes do exist, he does not describe any example of such a marsh at present sea-level, nor any example of a marsh formed according to the Shaler theory and later developing into the Mudge-Davis type due to relative rise of sea-level since its initial Shaler stages were completed. The Killam's Point salt marsh, which will be described herein, seems to be of the latter category and to show in the same marsh features confirmatory of the Mudge-Davis theory, already so well substantiated by an abundance of facts, together with features which definitely support the Shaler theory for which field evidence is, by the very nature of the case, so rare.

The Killam's Point marsh appears to be a fragment of a once larger marsh that seems to have commenced its growth very late during the post-glacial relative rise of sea-level, due to temporary and local conditions then prevailing.

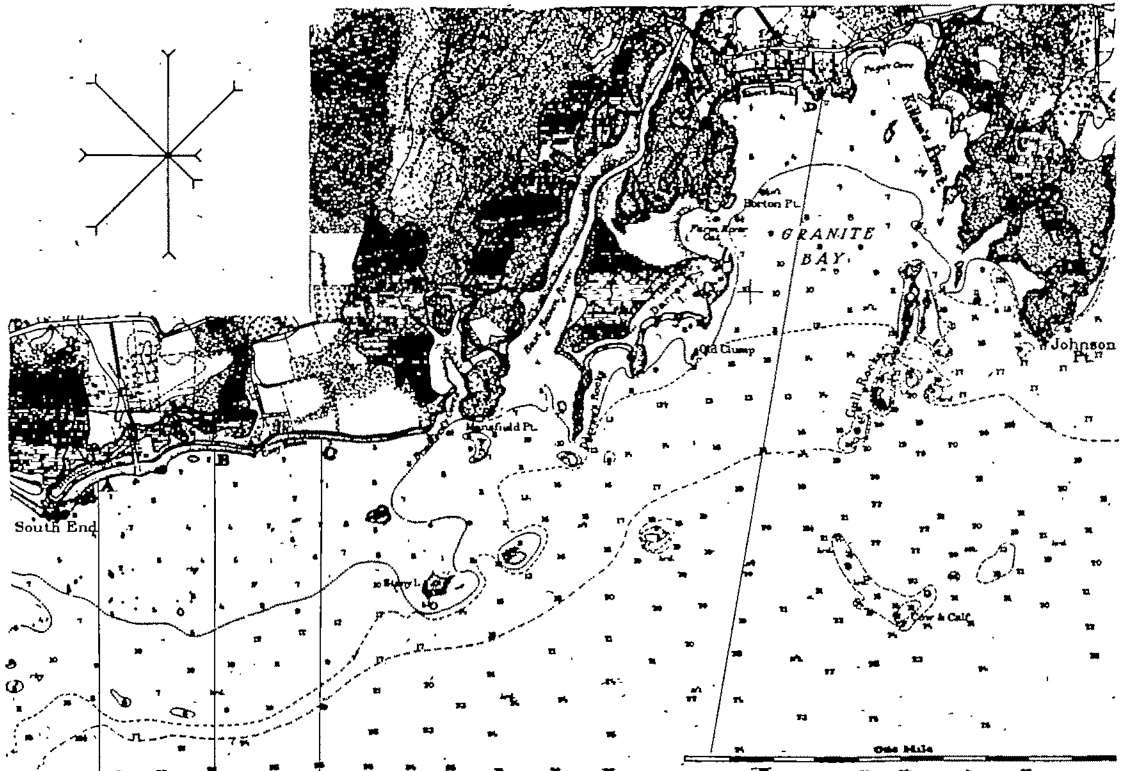

Fig. 1. Granite Bay and contiguous area along Connecticut Shore. The mouth of New Haven Harbor is a short distance to the west. From U. S. C. & G. S. chart No. 261 (Obsolete). Soundings in feet. Lines A, B, C, and D refer to profiles shown in text figure 2.

The wind-rose from the New Haven area, shown in the upper left-hand corner, is taken from Sharp, H., Conn. State Geol. & Nat. Hist. Survey, Bull. 46, 1929.

THE GEOGRAPHIC AND GEOLOGIC SETTING.

Granite Bay[1] lies about three miles east of Morgan Point, the eastern limit of the harbor of New Haven, Connecticut, and is separated from Branford Harbor, just to the east, by Johnson's Point, of which Killam's Point forms the western half. Granite Bay is about three-quarters of a mile deep and about four-tenths of a mile wide at the entrance between Darrow's Island (now known locally as Kelsey's Island) and the Gull Rocks. Its general features are shown in text figure 1. Bed rock on the surrounding shores is a granite gneiss dipping about ten degrees to the northwest which in the form of roches-moutonnées trending along the strike forms the higher elements on land and the various islands. The lower elements between the roches-moutonnées are occupied by glacio-fluviatile material, probably of slight thickness. The bottom of the bay shows little relief and slopes gradually in from the Sound with a depth of about fourteen feet at the entrance. (See text figure 2, D.)

The shores of the bay are predominately of bed-rock roches-moutonnées, with steep surfaces though at several points such as Short Beach, Page's Cove and the western half of the cove at Killam's Point there are sand and gravel beaches. At numerous points along the shore there are small masses of salt-marsh peat and at several points small areas of salt marsh with vertical faces of peat form the shore itself. Small areas of salt-marsh peat are present on the shoreward sides of the small rocky islands. In the Farm River cut (known locally as "the Gut") connecting Granite Bay on the west with East Haven River is a thriving salt marsh, its edges seemingly advancing over mud flats as postulated by Shaler's theory. This marsh is protected by a bed-rock barrier and a rock-tied beach from the waves of the open Sound and is not being cut back, at least on its lagoonal margins.

Though Granite Bay is sheltered on three sides, it is open to the southwest to the full sweep of the waves of Long Island Sound with a fetch of over twenty miles. Only wholly insignificant fresh-water streams flow into Granite Bay.

To the east of Granite Bay lies Branford Harbor, a bay similar in many respects to Granite Bay and probably with a similar history. It differs chiefly in that Branford River, a

[1] The bay is nameless on government maps and charts. The name here adopted has been used locally of recent years.

permanent stream enters the Sound through it. Directly to the west of Granite Bay is Darrow's Island, mentioned previously, separated by East Haven River from a line of sand and gravel beach that continues about two miles to the entrance of New Haven Harbor at Morgan Point. For the eastern quarter of the distance, that is along Cosy Beach, the beach is held by roches-moutonnées and from the western end of Cosy Beach to Morgan Point it is backed by salt marsh.

For about five-eighths of a mile off the beach between East Haven River and South End the water is shallow (less than

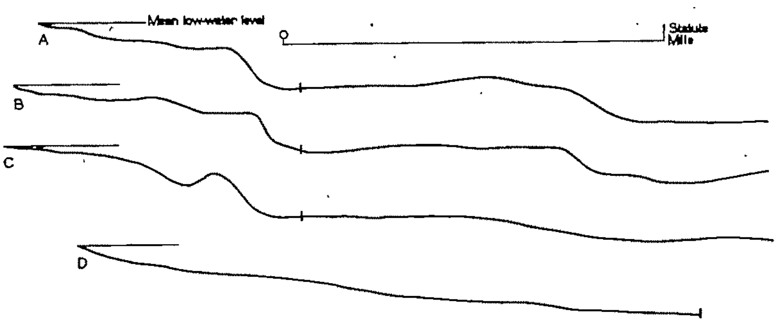

Fig. 2. Bottom profiles. A, B, and C. Profiles from just east of South End of Cosy Beach to show shelf-like shallows just off shore. C. Bottom profile of Granite Bay. Vertical scale greatly exaggerated.

two fathoms in depth) and is strewn with rocks and islands, some of them bed rock and others of erratics. About five-eighths of a mile off shore the bottom shelves off to twenty-four feet or more within a distance of fifty yards. This very marked shelf-like area, strewn as it is with rocks and islands some of which are composed of erratics, is manifestly a submarine, wave-cut terrace carved from glacial till by the waves of the Sound. Shore profiles are shown in text figure 2, A-C.

To complete the picture of the local setting still another factor of significance must be mentioned. A study of the wind-rose for the New Haven area (see text figure 1) shows that southwest winds here predominate overwhelmingly over all others as an effective agent in directing the transportion of shore debris supplied by the waves. Such debris must move eastward, and if supplied in sufficient quantity would be expected to close off reëntrants to the eastward by baymouth bars.

THE KILLAM'S POINT SALT MARSH.

Though there are numerous small patches of seemingly residual exposed salt marsh about Granite Bay and Killam's Point, the largest occupies an area about one-eighth of a mile long and about half as deep back of a double cove on Killam's Point. Marshes protected from the waves are not here considered. Within the cove is Sukee's Island, a granite-gneiss roche-moutonnée. On the shoreward side of the island is a much smaller area of salt marsh, up to fifty years ago continuous with the marsh area on the mainland. These relations are shown in text figure 3.

The western half of the marsh is somewhat protected by a sand and gravel beach but the eastern half, except for its northeastern corner and the continuation of the marsh on the east shore of the cove, presents vertical or overhanging faces of silty peat to the waves. About fifty years ago an attempt was made to hold the beach by placing a row of rocks along its crest and a dyke formed of two stone walls filled with earth was built across the salt meadows to the east, some distance within the then margin. Since that time the beach has held its position within any possibilities of measurement but the eastern half of the salt marsh has been cut back some sixty feet and much of the dyke has been undermined and destroyed. The isthmus of salt-marsh peat that formerly tied Sukee's Island to the shore has also been broken through and largely destroyed. This is shown on the sketch map, text figure 3.

The salt marsh, both on the mainland and on the shoreward side of Sukee's Island, has as a surface cover a luxuriant growth of the grasses of the *Spartina patens* association. *Spartina stricta* grows only at points about the edges where the surface has been cut locally below the zone of the *S. patens* association or on the banks of the very small creek that drains the main body of the marsh.

The cove itself has a mud bottom, as has Granite Bay and indeed much of the Sound in this region, but the mud, in reality a silt full of organic matter, is but a veneer, at least throughout the extensive area exposed by extreme low tides. Except at the northwestern margin close to the shore where glacial-fluviatile material is met with, the remains of *Spartina stricta* are found in place a few inches below the surface of the black, shelly silt. This appears to be clear proof that the cove as it now exists has been cut from what was formerly a

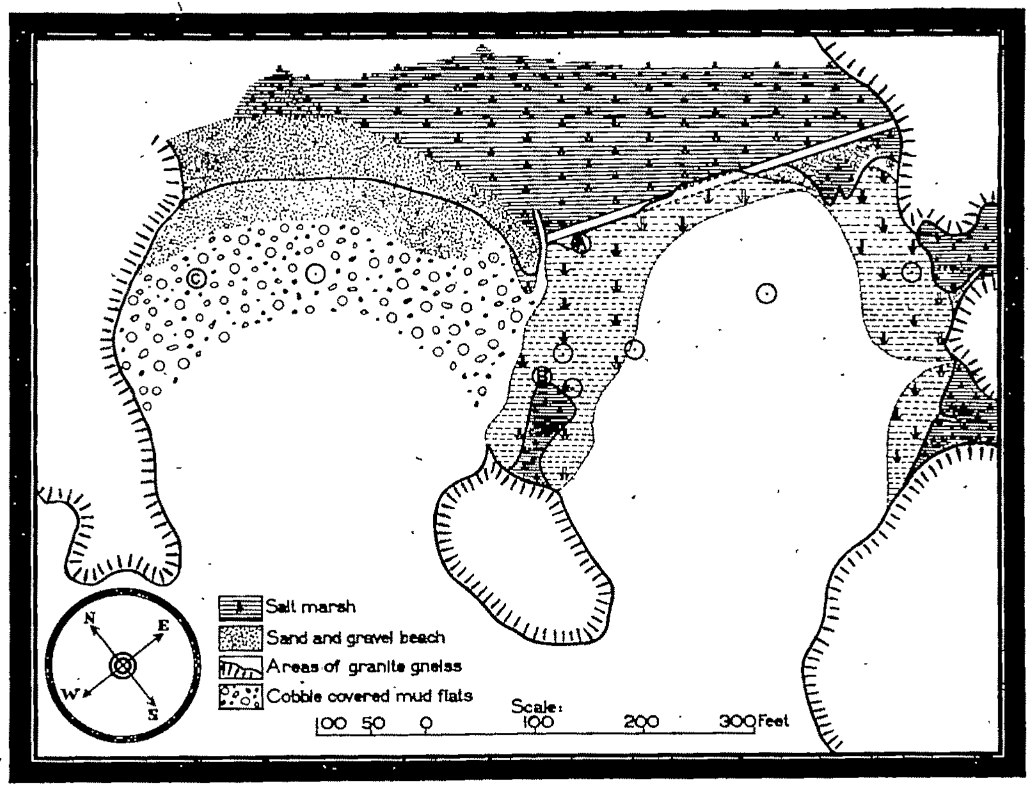

Fig. 3. The Killam's Point Cove. The dashed areas of Salt Marsh have been removed by the waves in the last fifty years. Data taken from an old property survey in the possession of Miss Alice Murphy of Killam's Point. The circles show locations of pits. For section shown in pits A and B, see text figure 4.

salt marsh of considerably greater area than the present one, and that the areas of marsh now remaining both on the mainland and on Sukee's Island are residuals of the larger marsh. It is a matter of historical fact, as shown in text figure 3, that at the very least the inner sixty feet of the eastern half of the cove has been so cut and that much in the last fifty years.

In passing it may be mentioned that the maintenance of the beach in the western half of the cove may be attributed to the fact that at its western end it is underlain by glacial material.

How the salt marsh, now unable to maintain itself against the assault of the waves, could have become established in the first place is a question that immediately arises. The answer to the question was found beneath the marsh itself and that answer, given quite definitely, seems to find confirmation in the geological and physical setting of the neighborhood as described in previous pages.

MARSH SECTIONS AND THEIR SIGNIFICANCE.

Taking advantage of the low tides of winter which frequently reach greater extremes than those of other times of the year a number of pits were dug at various points about the cove at Killam's Point, some in areas from which mature salt marsh is known to have been removed within the last fifty years and some in areas where there is no historical record of anything but mud bottom. All of the pits except one showed remains of *Spartina stricta* in place well below present mean low-tide level, often interbedded with layers of silt containing marine shells. The single exception at the northwest corner of the cove (Pit C, text figure 3) where red sand seemingly of glacio-fluviatile origin was met with below the few inches of black mud that is nearly everywhere present. Several of the pits were dug close to the vertical front of the residual marsh and these with the exposure in the face itself gave excellent sections from the top of the mature marsh to the bottom of the pit dug at its foot. This serves to demonstrate that the *S. stricta* peat below present low-tide level is in place beyond any possibility of doubt. Two of these sections are shown diagrammatically as text figure 4. The sections shown were chosen because they were so located at points at the foot of the vertical wall of eroded peat that they gave a clean

section of the whole thickness of the marsh to the bottom of the pits. These are quite typical of the others, which vary only in their details.

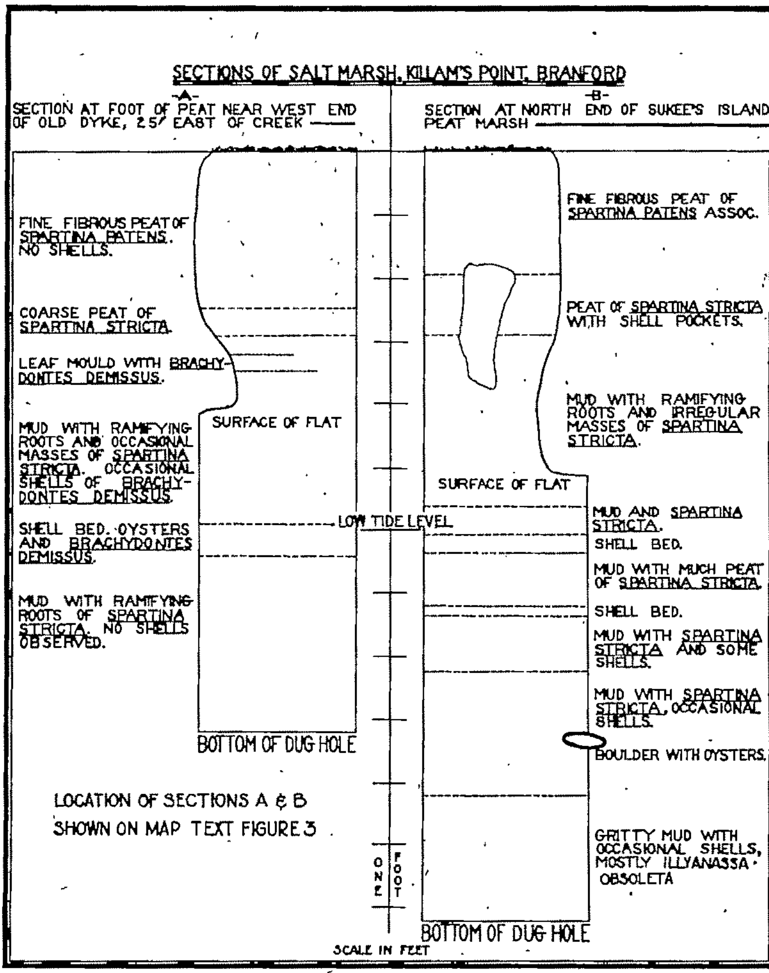

Fig. 4.

The reader's attention is called particularly to the following facts:

(1) Peat that is composed of or includes remains in place of the *S. patens* association is found to about two and one-half feet below the present surface of the marsh.

(2). Peat composed of, or silt containing remains of, *S. stricta* in place is found at least four feet below present mean low-tide level.[2]

(3) Layers of shells seemingly continuous below much of the former extent of the marsh.

The first two features stressed are confirmatory of the Mudge-Davis hypothesis of salt-marsh formation in its broader implication of a relative rise of sea level, but the well-marked superposition of the *S. patens* association over remains of *S. stricta* suggests the Shaler hypothesis as it would be formulated, with regard to later knowledge of the ecology of the salt-marsh flora. The third feature, especially when studied in its details, insists that at least the area of the marsh formerly occupying the Killam's Point cove was at some period before the botanical maturity of the marsh, a sheltered lagoon. The three features taken together imply that the marsh developed as a Shaler marsh and then under the influence of the relative rise of sea-level acquired some of the characters of a Mudge-Davis marsh.

The details of the shell-bearing beds are interesting and significant as to the ecology at the time of formation.

The shell beds of Section B, text figure 4, typical of much of the area exposed by pits, and the thickest section examined, will be taken as an example for closer study. The shell deposits in this section may first be divided from above downward into two types; (1) irregular pockets of shells; and (2) seemingly continuous beds. The latter may again be divided from above downward into three subtypes; a. continuous beds of shells in which *Brachydontes demissus* (the ribbed mussel) and *Ostrea virginica* (the common oyster), the latter in position of growth and attached almost exclusively to free valves of the former, form the most conspicuous element; b. beds of silt containing scattered shells, amongst which oysters in position of growth, are again conspicuous; and c. beds of gritty silt with occasional specimens, usually of *Ilyanassa obsoleta* (the mud snail).

The irregular pockets of shells (type 1) occur in a bed of salt thatch peat about one and one-half feet thick which lies at this point about two feet below the present surface of the marsh. The species represented in them are the most varied

[2] Mean low-tide level was not determined accurately but is taken as the level most commonly reached by low tides as observed by one living in the neighborhood, a level about six feet below the surface of the marsh.

of any of the shell deposits and the pockets themselves seem to have been formed as accumulations of dead shells washed into re-entrants of the advancing face of the growing salt marsh, and were subsequently overgrown by the marsh in its advance. Such accumulations may be seen in such re-entrants of growing salt marshes. Since such accumulations represent a fair cross section of the molluscan fauna of the mud flats and of the marsh itself, a list of the species found in one of them is given as an appendix. Most numerous amongst the gastropods are: *Littorina irrorata, L. rudis, L. palliata, Ilyanassa obsoleta, Melampus lineatus, Cingula aculea, C. minuta, Odostomia trfida, O. bisuturalis* and *Bittium alternatum.* Amongst the pelecypods *Brachydontes demissus, Ostrea virginica, Mya arenaria* and *Gemma gemma* are conspicuous in point of numbers. *Mytilus edulis* on the other hand is conspicuous in its absence from the pockets and the more continuous deposits lower in the section. *Littorina litorea,* as is well known, is an immigrant of only fifty years standing in American waters and though an abundant element in the present-day salt-marsh fauna, does not appear in the fossil-shell deposits here considered.

The significance of the presence of *Littorina irrorata,* a distinctly southern species, has been discussed in a previous paper (3). It does not seem to be living in Long Island Sound to-day, or if it is, it is exceedingly rare and confined to most sheltered habitats.

In the two upper bedded shell deposits (types 2a and 2b), the common oyster and the ribbed mussel are the most conspicuous elements, the former, as mentioned above, in position of growth, though the latter generally as free valves and seemingly never in position of growth. *Mya arenaria* is also found in position of growth and *Ilyanassa obsoleta* is abundant. *Littorina rudis* and *L. palliata* are moderately abundant and *L. irrorata* is present though not so abundant as in the pocket deposits (type 1). These deposits range from a few inches below present low-tide level to about four feet below that level. In the upper two feet of the zone (type 2a) the shells occur in a more or less continuous layer, embedded in silt which carries irregular masses of salt-thatch peat in position of growth. In the lower two feet (type 2b) the shells are more scattered and instead of masses of salt-thatch peat there are only rather sparse roots of salt thatch ramifying through the fine silt. In the lower part of the zone a granite boulder of

about the size of a paving cobble was found with oysters attached in position of growth. The significance of this boulder is not known.

The lowest deposits reached in the pit, down to about twelve feet below the surface of the marsh and about six feet below low-tide level, carry only occasional shells, chiefly of *Ilyanassa obsoleta*. No vegetable remains were noted except one or two leaves of eel grass, not in position of growth, and hence of no significance. The silt in this zone is quite gritty. What lies below this, the lowest point reached, is not known.

Zone 2a, packed with shells of the species described, is known to be quite widespread, seemingly as a continuous stratum, at least in the eastern half of the cove where most of the pits were dug. The association of species occurring most abundantly, particularly the great abundance of shells of *Brachydontes demissus*, *L. rudis* and *L. palliata*, is very different from what one may find on the bottom of the open cove to-day. It is indeed such an association as one can find only on bottoms of well-protected areas of mud flat surrounded by growing salt marsh, or in the larger salt-marsh creeks. *B. demissus* lives only within three or four feet of high-tide level and it is only abundant enough that its dead shells may virtually cover the bottom in the close proximity to a salt marsh, its optimum habitat. To find abundant living examples of *L. rudis* and *L. palliata* in the neighborhood to-day, one must go to the sheltered, salt-marsh lagoon behind Darrow's Island. That these shell deposits were formed on the mud flats of a protected lagoon seems a reasonable inference. It seems safe to rule out the other possibility, that they were formed in the bottom of a tidal salt-marsh creek as it shifted its position over the marsh, on the grounds that the area seemingly underlain by the continuous deposits is too large and that the area of the marsh itself, as evidenced by the condition in the present remnant, was too small to support a tidal creek of sufficient size to afford a suitable habitat. The present remnant of the marsh has only a single tidal creek about two feet in width.

The deposit of zone 2b may be interpreted as having had a similar origin to zone 2a at an earlier time when the advancing border of the marsh was farther away. Zone 2c seems to have been formed at a still earlier stage, below the then zone of salt thatch and perhaps below the then low-tide level. It should be mentioned, however, that the area underlain by these

latter zones is not well known since only a few pits penetrated below zone 2a.

At the level of the shell pockets (type 1) but in the face of the marsh at the northeast corner of the eastern half of the cove there is a concentration of logs, one of them bored by *Teredo*. The last is certainly marine driftwood.

Summarizing the conclusions drawn from the study of sections of the Killam's Point marsh, both the order of superposition of the salt-marsh grasses and the sediments below them and the molluscan association found in the sediments suggest very strongly that the marsh was originally formed by the silting up of a protected lagoon in essential accordance with Shaler's theory of salt-marsh formation. The presence of the *Spartina patens* association to a depth of about three feet below present high-tide level and of *Spartina stricta* to a depth of at least four feet below present low-tide level shows that there has been a relative rise of sea level of at least two feet since the marsh at this point reached botanical maturity, that is, since it acquired an essentially continuous mantle of grasses of the *S. patens* association and at least four feet since the bottom of the lagoon had been locally filled to a level where *S. stricta* could grow. This is in accord with the Mudge-Davis hypothesis.

THE HISTORY OF THE MARSH.

The material available for reconstructing the history of the marsh is partly in the form of facts and partly in inferences from other facts. This material may be summarized as follows:

(1) The small patches of salt marsh on the shores of Granite Bay and on the shoreward side of the islands in the bay are residuals of a once far longer marsh now being destroyed by the waves. This is an inference drawn from the facts that; (a) the present patches of marsh are being now rapidly cut away; (b) where pits have been dug in the mud flats exposed at low tide, remains of salt-marsh grasses in place are found below them; (c) one of the islands was known to have been connected with the mainland by continuous salt marsh in the memory of living persons and a second is known to have been so connected something over one hundred years ago.[3]

[3] Mr. James Bradley, now over eighty, informed me that his grandfather had told him as a boy that the island in Page's Cove was so connected with the shore in the grandfather's youth.

(2) The marsh as exemplified by the large residual mass at Killam's Point was formed as a Shaler marsh in a protected lagoon. This is an inference based on the botanical and sedimentary succession in the marsh and on the molluscan fauna found fossil within the marsh deposits.

(3) The area is a part of one in which there has been a long continued and general relative rise of sea-level. A fact attested by many physiographic features well known to students of the region and finding confirmation in the relations of the floral zones in the peat of the Killam's Point marsh to present tide levels.

(4) Directly to the west of Granite Bay there is an area from which a large mass of till was removed by the waves under the influence of predominantly southwesterly winds. This is an inference from the fact of the existence in that area of an extensive shelf covered with shallow water and strewn with rocks, many of which are erratics.

When the waters of Long Island Sound first entered Granite Bay, which was relatively free from glacial deposits, no salt-marsh grasses could maintain themselves since the bay was then, as it is to-day, exposed to the full sweep of waves from the southwest with a fetch of over twenty miles. The original bottom was probably somewhat lower than the present one and if it had ever supported a fresh-water marsh all evidence of it was removed by the waves. At some point of the water's slow advance over the land it met with a mass of glacial debris just to the west of the bay and the abundance of detritus thus supplied to the waves led to the formation under the influence of the prevailing southwest winds of a bay-mouth bar which included at least the Gull Rocks in its embrace. There was no doubt an opening in the bar for the passage of tidal water and for the egress of the waters of East Haven River, but Granite Bay as a whole became a protected body of water and salt-marsh grasses were able to gain a foothold about the margins, free from effective interference from the waves. Sediment swept in with the tides and from the land gradually silted up the waters and as the resulting mud flats reached a suitable level above low tide the marsh advanced over them. In the lagoon flourished a molluscan fauna appropriate to such a situation, the remains of which we now find buried in the sediments beneath the marsh, and into the reëntrants of the advancing marsh face were washed many shells to form the higher pocket deposits.

As the lagoon was silted up the relative level of the Sound waters rose but not so fast as the silting. Hence the net effect on the mud bottoms was silting alone while the effect on the areas which had been filled to a height above low tide that permitted the growth of the salt-marsh grasses was to thicken the deposits bearing their remains beyond that thickness which could have been developed with a stationary sea-level. After areas reached botanical maturity the increase in thickness affected the zone of the *Spartina patens* association alone.

While the marsh was being slowly transformed from a Shaler marsh to a Mudge-Davis marsh through the agency of the relative rise of sea-level, the mass of glacial débris to the west was being destroyed by the waves aided by the same agency, and continued an adequate supply of detritus to maintain the bay-mouth bar which probably retrograded approximately as the face of the morainal material was cut back. Finally, the supply of detritus was no longer forthcoming in adequate amount, the bay-mouth bar, long since a beach bordering an extensive salt marsh, was removed by the same forces that had brought it its nourishment while available, and the silty and peaty lagoon filling, no longer protected, was rapidly removed by the waves from nearly the whole area.

To-day we see only small residual patches of marsh and they are being cut away almost visibly. Just why the supply of detritus became insufficient to maintain the bay-mouth bar is not so clear. Perhaps the morainal mass was completely destroyed or more likely the effectiveness of the waves was greatly reduced owing to the increase in width of the shallow wave-cut platform and the consequent dissipation of their energy in their efforts to lower it, a task made more difficult through the concentration of larger erratics on its surface and the exposure of considerable areas of bed-rock. Perhaps a cessation of the rise in sea-level reduced the efficacy of the waves below the point where they could continue to supply detritus in volume adequate to maintain the bar. Perhaps each of these and other factors contributed. At any rate there is no bar across the bay to-day although its existence for a long time in the past seems a necessary inference if we are to account for the salt marshes.

GENERAL CONSIDERATIONS.

The Killam's Point salt marsh and the history of the inferred much larger Granite Bay salt marsh, of which the

former seems to be a small residuum, have an important bearing on our concepts of marsh formation. The Killam's Point marsh seems to be the first recorded to give definite field evidence of the early stages of marsh formation so rarely preserved, coupled with equally definite evidence of the effects of a steady rise of sea-level. Thus we have evidence in at least this instance that both the Shaler and Mudge-Davis theories are valid though each for a different stage of development of the same marsh. The vast majority of the New England salt marshes are through-and-through Mudge-Davis marshes insofar as we may discover from those parts of them preserved to us. And yet it seems necessary to assume that most, if not all, of them began as Shaler marshes, in spite of the rarity of confirmatory field evidence that they did so.

Great areas of New England coast are occupied by marginal marshes protected from the direct action of the waves by beaches of sand, shingle or of cobbles. This is one of the factors that led Shaler to adopt his theory. It does not seem possible that salt-marsh grasses could either obtain a foothold or continue to grow without protection from the waves or for any area to be initially silted to the level for the development of a marsh unless the process received protection. Such protection was supplied in the very nature of the case where marshes came to occupy estuaries, but a bar of some sort seems necessary for the development of any marginal marshes at all. And as such bars usually form in water too deep to allow the growth of salt-marsh grasses, a silting up is a necessary preliminary to their growth. Since *Spartina stricta* grows at lower levels than the *S. patens* association and since it will grow first where bottom has been raised first to the requisite height above low-tide level, that is, close to the shores of the lagoon, the marsh mass will commence its growth in these positions and advance out over the mud flats as they are raised to the requisite level, with *S. stricta* below and *S. patens* association above. This is the essence of the Shaler theory. In an area of subsiding coast or rising sea-level, providing the relative rise does not take place at a rate faster than that at which the grasses aided by mechanical sediments can form peat, the surface of the marsh will rise with the rise in sea-level and where the marsh is botanically mature the increment in thickness will be, in simple cases, supplied entirely by the *S. patens* association. As the sea-level rises the marsh will advance over the land which is protected, be it remembered, at

all times from wave erosion. The advancing salt marsh may then bury undisturbed fresh-water marsh, forest, or any other low-lying surface feature.

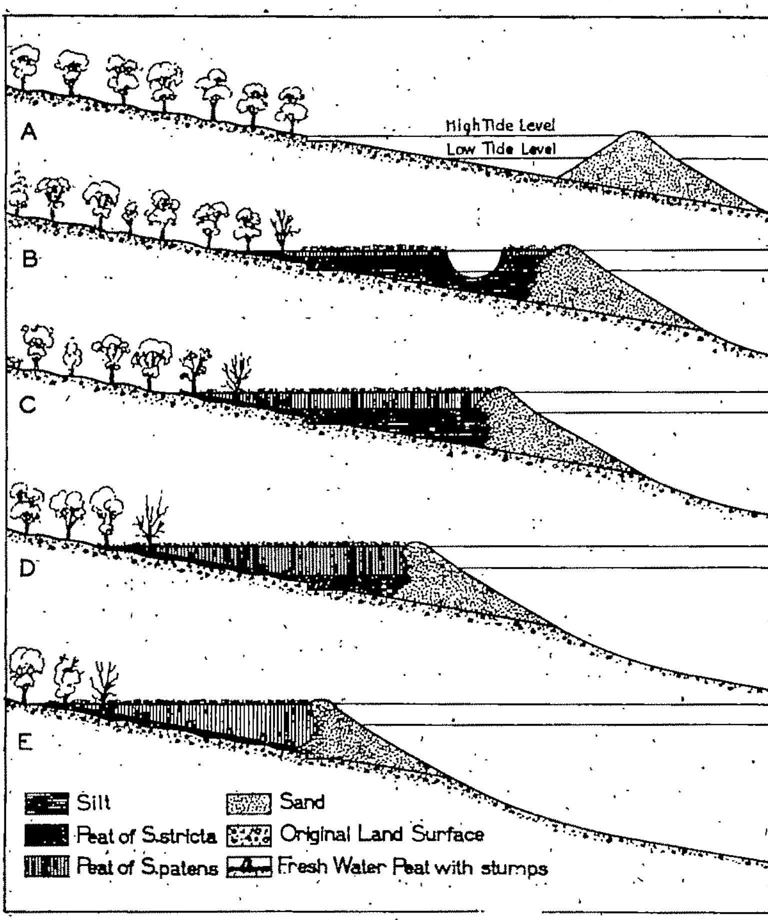

Fig. 5. Diagram to illustrate stages in the theoretical constructional history of a typical New England salt marsh. A rising sea-level predicated throughout. (B) A slightly modified Shaler marsh. (C) A modified Shaler marsh at something like the stage reached by the Granite Bay Marsh before removal of the bar and destruction of the main body of the marsh. (E) Final Stage. A Mudge-Davis marsh throughout. All traces of the original Shaler marsh destroyed.

The bars and beaches have been spoken of as protecting the lagoon and the marshes. They are not, of course, a complete protection, for storm waves may erode the marsh deposits in

spite of them or throw the beach bodily onto the margin of the marsh itself. The bar, now a beach, will thus commonly retrograde and the seaward edge of the original Shaler marsh and eventually all of it will be either eroded away or buried beneath deposits to the seaward of the beach. Hence, unless, as in the case of the Killam's Point marsh, the conditions for the existence of any marsh at all occurred late in the era of rising sea-level, or unless special and local conditions intervene, there will be no remaining evidence in the marsh of any Shaler features. The marsh will then be a Mudge-Davis marsh, though none the less the direct descendant of a Shaler marsh and wholly dependent for its origin on the original Shaler marsh.

The theoretical history of a marginal salt marsh of the New England type is shown diagrammatically as text figure 5. A marsh in an estuary would have a history differing only in detail but with more possibilities for variation from type, particularly in its earlier stages, since the shores of the estuary were not subject to the attack of the waves, and at first may have been under the influence of fresh or brackish water. Indeed, in such situations, salt water may have initially covered some areas at high tide so shallowly that the *S. patens* association may have found favorable conditions from the start.

ACKNOWLEDGMENTS.

Acknowledgments are due a number of my friends then graduate students at Yale for assistance in the interesting but unpleasant task of digging pits in the mud flats at Killam's Point. Chief among these are Mr. F. Earl Ingerson, Mr. Russel M. Logie, and Mr. Lyndon Morrow. Professors R. F. Flint and Carl O. Dunbar have been good enough to check my observations in the field and Professor Dunbar has rendered aid in many other ways. Professor G. E. Nichols of Yale was also good enough to check my botanical data on the ground, and has given me far more information on his subject than space will permit me to use here. I am under deep obligations to Professor Douglas Johnson of Columbia University for encouragement and especially for a most careful and full criticism of my manuscript in its original form. I am also indebted to my friend Mr. John Killam Murphy and his family of Killam's Point for permission to dig pits and for information as to conditions years ago.

APPENDIX.

About three gallons of mud were taken from one of the pocket deposits of shells. The mud was washed and the shells picked from the washings and counted. Each pelecypod valve was counted as one specimen. It must be remembered that the pocket deposits are interpreted as collections of shells, probably a fair cross section of the molluscan fauna of the lagoon, washed into the reëntrants of the advancing marsh face above low-tide level. No forms were in the position of growth and some of them, notably the oyster, are represented largely by juveniles, though mature specimens are abundant in the continuous shell beds at lower levels.

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3. Knight, J. B. *Littorina irrorata*, a post-Pleistocene fossil in Connecticut, this Journal, 26, pp. 130-133, 1933.

SPECIES.

	No. of Specimens
Gastropods	
Acteon punctostriatus (Adams)	1
Anachis avara similis (Ravenal)	11
Astyris lunata (Say)	33
Bittium alternatum (Say)	1700
Busycon canaliculatum (Linné) (1)	2
Cingula aculeus (Gould) Cingula minuta (Totten) } (3)	387
Crepidula convexa Say	62
Eupleura caudata (Say)	1
Ilyanassa obsoleta (Say)	308
Lacuna vincta (Montagu)	5
Littorina irrorata (Say)	33
Littorina palliata (Say)	170
Littornia rudis (Donovan)	471
Mangilia plicata (Adams)	1
Melampus lineatus (Say)	171
Odostomia trifida (Totten) Odostomia bisuturalis (Say) } (3)	57
Pyrimidella fusca (Adams)	7
Tritia trivitatta (Say)	21
Tornatina canaliculata (Say)	27
Turbonilla sp.	1
Urosolpinx cinereus (Say)	13

Pelecypods

Anomia simplex D'Orbigny	5
Arca campechiensis pexata Say (1)	13
Arca transversa Say (1)	3
Brachydontes demissus (Dillwyn) (4)	54
Gemma gemma (Totten)	163
Laevicardium mortoni (Conrad)	5
Macoma tenta Say	4
Mulinia lateralis (Say)	4
Mya arenaria Linné (2)	40
Ostrea verginica Gmelin (2)	104
Pecten gibbus borealis Say (2)	6
Rochfortia planulata (Stimpson)	1
Tellina tenera Say	3
Teredo sp.	?
Venus mercenaria Linné (1)	11

(1) Juvenile specimens.
(2) Mostly juvenile specimens.
(3) Not specifically separated.
(4) The thin, pearly shell of *B. demissus* disintegrates rapidly on burial in the mud and only fairly large fragments were counted.

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MINERAL ORIENTATION IN SOME ROCKS OF THE SHUSWAP TERRANE AS A CLUE TO THEIR METAMORPHISM.[1]

JAMES GILLULY.

ABSTRACT.

A brief summary of some of the principal concepts of petrotectonics is given and the methods used are outlined. As an illustration of one of the many possible applications of these methods, two rocks from the Shuswap terrane of British Columbia have been studied, the orientations of their component quartz and biotite grains determined, and the statistical orientations of these grains compared with the orientations to be expected on the theories of static metamorphism and dynamic metamorphism. The grain orientations shown by these rocks are analogous to those common in the great Alpine overthrust sheets and are believed to be incompatible with a metamorphism under static conditions. Attention is called to the fact that in these rocks, as in nearly all others so far examined, the orientations of the mineral grains give no support to the theory that mica parallelism and rock cleavage form in the plane of rock elongation. Instead they strongly suggest that the schistosity is in shear planes. Attention is also called to the fact, already emphasized by Sander, that linear parallelism of minerals in metamorphic rocks, although lying in shear planes, may be normal to the direction of shearing displacements in them—hence not analogous to flow lines in igneous rocks. The linear elements in the Shuswap rocks seem clearly of this type. The widespread occurrence of linear elements of this kind necessitates caution in interpreting directions of motion in metamorphic rocks.

PETROTECTONICS.

Rocks may be classified according to origin, chemical or mineral composition, age, mode of deposition or on the basis of many other features. Each of these principles of classification is valuable in approaching certain geologic questions and each is meaningless in respect to others. Within the past twenty-five years an entirely distinct classification has been advanced by European workers as a basis for tectonic studies, namely, one based upon the spacial arrangement and orientation of the components of the rock—the rock fabric (Ger. Gefüge der Gesteine). The German word "Gefüge" has been translated as "fabric," although the term as used in Europe is more inclusive than is ordinarily connoted by fabric in America and embraces practically all spacial arrangements or geometric features of rocks and their components of whatever order of magnitude, from the crystal lattices of the component minerals to mountain structures.

[1] Published by permission of the Director, U. S. Geological Survey.

The leading contributors to the systematization of this aspect of structural geology are the Austrian geologists, Bruno Sander[2] and Walter Schmidt. The fundamental concept of these workers is that the fabric records in greater or less degree the symmetry of the vector fields under whose operation the rocks were formed or metamorphosed. This is regarded by Sander as a perfectly general rule and is ably supported in his great book by examples from many classes of rocks. However, it was first formulated from study of metamorphic rocks and has been most widely applied to them, and inasmuch as such rocks form the subject of this paper, the theorem is here considered only in its application to deformed rocks.

The fabric in the sense of these workers, as already stated, embraces all geometrical relationships of the rocks of whatever order of magnitude from that of the crystal-lattices of the component grains to those of field geology. There is nothing novel in the suggestion that the geometry of such features as joints, stratification surfaces, folds, faults and cleavage bears a direct, even though often indeterminate, relation to the stresses operating (and the movements resulting) in rock masses, although both Schmidt and Sander have also made decided contributions in this field. The outstanding advance made by these men, however, has been the statistical demonstration that the geometry of the grain fabric, that is, the fabric as expressed in the grains composing the rock, is commonly a direct correlative of the deforming movements. In fact, rocks whose deformation by means of mutual differential movements of the component particles (penetrative movement or *Durchbewegung*) has been recorded in their grain fabrics are set apart as a great class of rocks—the tectonites—which are distinct from those that have not undergone such penetrative differential movement—the non-tectonites. The tectonites include probably all gneisses, both protoclastic and cataclastic, and those schists and phyllites that have been "dynamically" deformed; the non-tectonites include a few phyllites and almost all hornfelses as well as all undeformed igneous and sedimentary rocks.

[2] The numerous contributions of these authors have been recently summarized in their books: Sander, Gefügekunde der Gesteine, 1930, Julius Springer, Wien; and Schmidt, Tektonik und Verformungslehre, 1932, Gebrüder Borntraeger, Berlin. A concise discussion of their work, apparently the first to appear in English, has recently been published: E. B. Knopf, Petrotectonics, Amer. Jour. Sci., vol. 25, pp. 433-470, 1933.

One of the fundamental concepts of petrogeometry is that of fabric symmetry. The symmetry may be expressed in the following ways:

1. By the orientation of individual crystals, either
   a. according to their grain shapes (external form).
   b. according to their crystal lattices (internal structure).
2. By the intergrain lattice (Ger. Intergranulare), which is defined as the common bounding surface of all the grains composing the rock (analogous to a honeycomb). This lattice may be regarded as purely geometrical, or as the physically and chemically heterogeneous intergranular film separating all the individually homogeneous fabric-regions. This intergrain lattice commonly includes such surfaces of discontinuity as bedding, cleavage, or schistosity of whatever origin.
3. By the spacial relations and mutual orientations of the so-called part-fabrics, such as the fabrics of
   a. grains including, or
   b. included in, other grains.
   c. penetrations.
   d. intergrowths, etc.
4. By the relations between shapes of grains and their crystallographic directions.

The symmetry of such a fabric is of course only approximate in any rock mass and is determinable only by statistical methods; that is, one direction in which a majority of grains have similar properties, certain deviations being permitted, is to be compared with a second direction in which the same is true. Such statistical approximation to symmetry has been recognized by Schmidt and Sander to be one of the most general properties of rocks and has been observed in the grain fabrics of both tectonites (in schists, mylonites, etc.) and non-tectonites (tufa, sandstones, vein quartz, etc.).

The recognition of symmetry and the comparison of symmetry patterns are facilitated by the reference of the space data to three conventional mutually normal axes, lettered, like the axes of crystallography, *a*, *b*, and *c*. *Within the rock volume considered*, these coördinates have been arbitrarily chosen by Sander (for metamorphic rocks) as follows: The most prominent surface of schistosity is the *ab* plane and the *c*-axis is normal to it. Within the *ab* plane, *b* is chosen parallel to the axes of drag folds, or to the intersection of secondary schist planes. The *a*-axis is then transverse to the strike of the local structure. The usual plane of a geologic cross section of a mass (whether a mountain range or masses of smaller size

even down to hand specimens) would be the *ac* plane. A striking feature that recurs if such rock features as joints are referred to these axes by Miller indices, is the common presence of joints with one or two zeros in their symbols; that is, the principal planes of schistosity are 001 planes, the subordinate cleavages are h0l planes, the cross-joints are 0k0 planes, etc. The *b*-axis has been called by Schmidt the tectonic strike even though it may be locally steeply tilted. It is unfortunate that the term "tectonic strike" has been used for this direction as it is strictly applicable only to structures with horizontal axes. The wide prevalence of plunging structures demands another term than "strike" or a departure from its common usage as the direction of a horizontal line. Since Sander has pointed out that some mountain structures have vertical *b*-axes—the term tectonic strike may become absurd. A simple term like *b*-axis, however, is not desirable as it is too technical. Perhaps "tectonic axis" is self-explanatory and sufficiently definite to serve usefully instead of Schmidt's term.

Statistical studies of homogeneous grain fabrics have permitted the recognition of the following symmetry classes:

A. Statistically isotropic: non-oriented fabric.
B. Statistically anisotropic: oriented fabric.
   1. Rotational; symmetry of the rotational ellipsoid.
   2. Rhombic; symmetry of the triaxial ellipsoid.
   3. Monoclinic; with symmetry plane and center.
   4. Triclinic; with symmetry center only.

ANALYSIS OF GRAIN-FABRIC.

The objective statistical demonstration that such symmetry patterns exist in grain fabrics was developed by Schmidt,[3] and has already led to many important results, not only in regard to theories of schistosity but also in the interpretation of major structures, determination of the relative date of a given deformation or intrusion and direction of fault displacements.

The essentials of the method are these: If conclusions as to regional movements are to be sought, the rock to be studied is marked as to orientation (both geographic and with reference to the local structures such as schistosity or fold axes) before being broken from the outcrop and thin sections of known orientation are prepared. Although it is possible to

[3] Schmidt, Walter, Gefügestatistik: Tschermaks Min. Petrograph. Mitt., Bd. 38, pp. 392-423, 1925.

obtain similar results with oblique sections, experience has shown that interpretation is facilitated by using sections cut (1) parallel to the schistosity (*ab* plane, with indices 001 referred to the standard axes, see p. ....), (2) parallel to the local tectonic axis (i.e., axes of minor folds) and normal to the schistosity (parallel to the bc plane, indices hOO on the reference axes) or (3) normal to the tectonic strike (parallel to the ac plane, OkO). For most purposes the second and third orientations are preferable.

The section whose grain fabric is to be studied is placed on a Federov stage equipped with a guiding ruler (Schmidt sledge, manufactured by Leitz) which permits shifting the section while retaining constant orientation. The minerals whose orientations have been chiefly studied are the uniaxial ones, quartz and calcite, and the micaceous minerals. A little work has been done on the feldspars and hornblende, but the more complex relations between their optic indicatrices and crystal forms have deterred workers from attacking them.

The data most commonly obtained are the orientations of the *c*-axes of quartz and calcite and the poles to the planes of the cleavage of calcite and the mica minerals. These orientations are determined on the universal stage in the usual manner[4] and the attitude of the axis or pole defined as follows: The grain is assumed to lie at the center of a reference sphere, its axis or pole is projected to intersect the surface of the sphere and this intersection is then projected onto the plane of the thin section as the equatorial plane of the sphere. Since every diameter intersects the surface in two points, there is a choice as to which intersection is to be used. By convention, following Schmidt, the lower hemisphere is the one projected.

Because of the statistical use to which the data are applied, the plotting is done not on the customary stereographic or angle-true azimuthal projection used in crystallographic work with the Federov stage, but upon a surface-true azimuthal projection (Schmidt net, sold by Leitz). On such projections a unit area in any position on the projection,—though naturally distorted in shape,—corresponds with a unit area of the surface of the sphere. The orientation of each grain being thus indicated by a point, it is possible to observe any statistical pre-

[4] The technique is described in detail in Sander, B., Gefügekunde der Gesteine, pp. 121-132, 1930, and in relation to the uniaxial minerals by Pabst, Adolf, "Pressure-shadows" and the measurement of the orientation of minerals in rocks: Amer. Mineralogist, vol. 16, pp. 55-70, 1931.

ference in these orientations. In order to obtain an objective measure of the degree of uniformity in such orientations, it is usual to go over the projection with a circle whose area bears a known relation to the area of the circle of projection, say 1 per cent or, if but few grains have been measured, 2 per cent, or 4 per cent. This is facilitated by placing the transparency upon which the axes were plotted on a piece of centimeter paper. The projection is then gone over systematically by putting the center of the unit circle in turn on all the intersections of the centimeter coördinates and counting the number of points in each such area. The Schmidt net as sold by Leitz is 10 centimeters in radius, hence 1 per cent of it is covered by a circle of 1 centimeter radius. These numbers of grains per unit of the surface are then contoured, the contour interval being arbitrarily selected to bring out contrast in concentration of axes. (It may be pointed out that the same symbols on the diagrams in Figs. 2-6 do not indicate identical concentrations.) Instead of reporting the concentration of axes simply in these numbers, which would be meaningless, the numbers are divided by the number of grains measured and reported on the contoured projections in terms of the percentage of all grains measured whose projections fall in 1 per cent (or 2 per cent or 4 per cent, respectively) of the reference sphere. A special transparent device is used in counting the grains at the border of the projection within the ring where the measuring circle falls in part outside the projection. Here, a moment's consideration shows, it is necessary to count points in enough of the diametrically opposed area of the projection to make up 1 per cent of the area. This is done by means of a celluloid rule with a longitudinal notch permitting it to slide along a pin in the center of the projection. At opposite ends of this rule unit circles are marked 20 cm. apart. The grains near the border of the projection are counted by placing the center of one of these circles on the centimeter squares and counting the points in both circles.

The symmetry and degree of uniformity of orientation of the minerals are thus objectively represented in the projections. As the degree of uniformity of orientation increases, fewer grains are required to show it. Poorly ordered rocks (rocks not characterized by a strongly preponderant orientation of their component minerals), however, may necessitate the measurement of many grains to bring out any symmetry. A measure of the reality of such orientations, as shown in such

diagrams as Figs. 2-6, is to be had by contouring successive numbers of projected points. If the maxima obtained in the first group of grains measured are also found as maxima in the next group of an equal number of grains, the presence of these statistical maxima (or minima) may be regarded as real and not due to accidental choice.

The development of this statistical method of presenting the orientation of the component grains of a rock has permitted considerable progress in structural study. Among the most important results has been the demonstration that the grain fabrics of many metamorphic rocks are direct correlatives of the larger structural features. In the same way that it has long been recognized that drag-folds have a definite relation to the folds of next higher order, it is now possible to demonstrate that similar relations obtain down to a statistical arrangement of the individual grains.

The orientation diagrams constructed in this way have been classified by Sander into two groups, the S-tectonites and the B-tectonites. The S-tectonites are characterized by concentrations of axes (maxima) about points, usually about *a*, or symmetrically with respect to *a*. The B- or girdle-tectonites are characterized by the concentrations of maxima in a girdle normal to *b*, the axis of both internal and external rotation during the deformation. In the rocks in which *b* has served as axis of external, as well as internal, rotation it is called the B-axis. The mechanics and the interpretation of these two general types of orientation have been exhaustively discussed by Sander and Schmidt and a brief review of the problem is given by Mrs. Knopf, so that it will not be discussed here in detail. It is highly probable, from the following considerations, that these orientations result from internal deformation in the rocks and the grain by grain rotation, either of the minerals themselves or of the seed crystals from which the present crystals grew.

1. The maxima can frequently be correlated with planes of gliding in the crystals, i.e., parallel to c' of quartz, to $-\frac{1}{2}\,\epsilon$ of calcite, to β' in the basal cleavage of muscovite, etc., so that they suggest that the crystals have rotated until they acquired a position favorable to gliding, after which they glided—or (in calcite and possibly in some quartz fabrics) twinned, with the twinning plane in the plane of schistosity.

2. In many rocks the reference of these maxima to shearing in the plane of schistosity is strongly supported by correlatable

shearing movements resulting in stretching of fossils, of conglomeratic pebbles, of amygdules in lavas, and also by the common occurrence of feldspar and pyrite porphyroblasts in unstable positions and in augen showing rotation of the porphyroblast during growth. The rotation of garnet porphyroblasts as demonstrated by entrained inclusions is a familiar example of the differential movement which can sometimes be correlated with the shearing movements postulated from the orientation diagrams of some of these minerals.

3. The reference of the dominating orientations of most minerals—as displayed by statistical methods—to movements affecting the individual grains is supported not only by these small-scale features but also by the fact that almost all the diagrams are referable to and correlate with the larger scale tectonic features such as drag-folds and overthrust planes. Sander and Schmidt have found that girdle-tectonites have their girdles normal to the axes of the drag-folds. When these axes change dip, the girdle does the same in a complementary sense. S-tectonites are commonly referable to gliding planes oriented the same as the major thrusts. This is found to be true in *both cataclastic* and *crystalloblastic* schists. Even where post-tectonic crystallization has proceeded so far as to mask entirely the cataclastic features, the orientation of the recrystallized minerals appears to be governed by seed crystals oriented conformably with the postulated differential movements.

APPLICATION TO THE SHUSWAP TERRANE.

It is the purpose in the remainder of the present paper to study, by these methods, the grain fabrics of some rocks of the Shuswap terrane in British Columbia in order to see what light may be thrown upon the processes involved in their metamorphism. These rocks were chosen for study because the principal work heretofore done in petrogeometry has been with the dynamo-metamorphosed rocks of the Alps. The symmetry systems existing in these rocks have been definitely correlated with the mountain structure. Since the Shuswap rocks have been regarded by Daly as load metamorphosed, I have thought it worth while to examine their grain fabrics in order to see what symmetry, if any, they possess and how this may be correlated with the movements, either molar or molecular, producing it—in short, to ascertain how the symmetry systems

of load-metamorphosed rocks contrast with the symmetry systems of dynamo-metamorphosed rocks. Through the kindness of Professor Daly in supplying half a dozen rock specimens from the Shuswap terrane, it has been possible to make this study.

THE SHUSWAP ROCKS.

The Shuswap terrane, cropping out over an area of thousands of square miles of the interior mountains of British Columbia, has been cited as an example of static or load metamorphism on a large scale. As described by Daly[5] these are pre-Cambrian metamorphic rocks and include hornblendic gneisses, mica schists, chlorite schists, quartzites, limestones, and phyllites intruded by granites and orthogneisses. About half the terrane is composed of a sill-sediment complex in lit-par-lit arrangement. In the field, these rocks commonly have their schistosity parallel—according to Daly "rigorously" parallel—to the original bedding. Over broad areas the formations dip at low angles and the average of dips for the entire terrane is about 35°. The flat-lying rocks are fully as coarsely crystalline as those standing vertically. Ordinary folds are remarkably rare and the deformation that the rocks have undergone seems to be due chiefly to normal faulting and tilting. Overthrusting is conceivable but no evidence of it was found. Vertical dikes, through flat-lying sediments, have their schistosity parallel to the bedding of their country rocks.

Locally this terrane has later been deformed, during which narrow zones of schist and granite were sheared and partly recrystallized under control of tangential stress, as a result of which a second schistosity was superposed on the older. For all these reasons Daly concluded that the Shuswap terrane illustrates the effect of static metamorphism without tangential rock movements—a conclusion that had been anticipated, though on the basis of less detailed work, by Dawson.[6]

FABRIC TO BE EXPECTED UNDER STATIC METAMORPHISM.

If the grain fabric of a metamorphic rock is a correlative of the stresses active in the rock during metamorphism, and static metamorphism involves simply radial stresses in the

[5] Daly, R. A., A geological reconnaissance between Golden and Kamloops, B. C. along the Canadian Pacific Railway: Geological Survey of Canada, Mem. 68, pp. 10-57, 1915.

[6] Dawson, G. M., Geological record of the Rocky Mountain region in Canada: Geol. Soc. Amer. Bull., vol. 12, p. 64, 1901.

earth's crust, one would expect, in statically metamorphosed rocks, a grain fabric symmetrical to the radius of the earth. In view of Daly's conclusion that the Shuswap terrane was metamorphosed to its present grade before the rocks were disturbed from their horizontal position, this would mean that the grain fabric of the rocks should be symmetrical to a normal to the schistosity. This should be true whether the schistosity is a result of mechanical flattening of heterogeneously arranged inequidimensional grains or of recrystallization according to Riecke's principle, which would favor the growth of seed crystals oriented with their directions of readiest growth normal to the maximum stress. The study of these supposedly statically metamorphosed rocks has therefore been interesting, since here, if anywhere, should be expected evidence of the effectiveness of Riecke's principle—and especially since all the statistical studies of grain fabric of dynamometamorphosed rocks so far published have failed to produce any evidence for its control of flow cleavage as postulated by Becke, Van Hise, Leith, Daly, and other students of metamorphism.

EXAMINATION OF THE ROCKS.

Of the half-dozen specimens so kindly made available by Professor Daly, two were selected because of their better schistosity and the fact that they are rich in quartz and mica, minerals whose orientation is readily studied. The rocks selected were a hornblende-biotite schist from near Albert Canyon station (dip 55° ?), and a biotite gneiss from Seymour Arm, Shuswap Lake (dip 30°). Both rocks are quartzose, carry considerable epidote, zoisite, and alkaline feldspar, with some intermediate plagioclase. The texture is lepidoblastic except that the quartz and, to a less degree, the hornblende show some cataclastic effects, principally "strain shadows."

Even before having oriented sections cut, it was apparent that the grain fabric would in all likelihood not be symmetrical with respect to a normal to the schistosity, because there is a pronounced linear parallelism of minerals within the plane of schistosity. (See Fig. 1 which may serve as a sketch of the gneiss specimen studied.) Furthermore, although the schistosity in the biotite schist appears very definite and in planes rigorously parallel, that in the gneiss is composite and wavy, so that the rock, when viewed along the direction of the linear parallelism, appears to be composed of lenses; when viewed

normal to the linear elements, however, the schistosity is nearly as regular as that of the biotite schist. These observations seem to indicate that within the plane of schistosity these rocks are, when treated statistically, anisotropic, showing preferred orientations of the component grains. Such a result is incompatible with pure static metamorphism, although it does not deny that load was an important factor in the metamorphism.

The assumption was made that this linear parallelism in the Shuswap rocks,—analogous to that most common in dynamically altered rocks—marks the axis *b*, of the reference coördinates mentioned above and shown in Fig. 1. Sections were

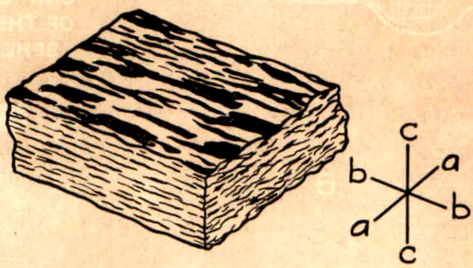


Fig. 1. Sketch of biotite gneiss, Seymour Arm, B. C. Showing linear as well as planar schistose elements.

then cut normal to this linear parallelism, i.e., embracing the assumed tectonic plane *ac*.

The statistical analyses of the orientation of the biotites and quartzes of the biotite schist are shown in Figs. 2 and 3, respectively. The point B marks the projection of the linear parallelism of the rock, *a-a* is the projection of the schistosity, *c* is normal to the schistosity. The projections of biotite axes show, in addition to the obvious fact that the biotite plates lie dominantly in the plane of schistosity, that the maximum is elongated in the *ac* plane as compared with its spread in the *bc* plane, indicating a more pronounced waviness in the schistosity normal to the linear parallelism than along it. The quartz diagram of Fig. 3 shows, confirming the correctness of the selection of reference axes, that the quartz grains of the rock tend to lie with their *c*-axes in a girdle normal to the linear parallelism of the rock. The quartz grains are not, however, elongated parallel to the prism. Practically all areas of the reference sphere where the concentration of axes is 2 or more times the expectancy under random distribution, namely, where

2 per cent or more of axes are contained in 1 per cent of sphere surface, lie on the circumference of the projection in the *ac* plane normal to B $=b$. It is true that this girdle is not absolutely closed, but it must be borne in mind that these are statistical orientations and it is not to be expected that they would

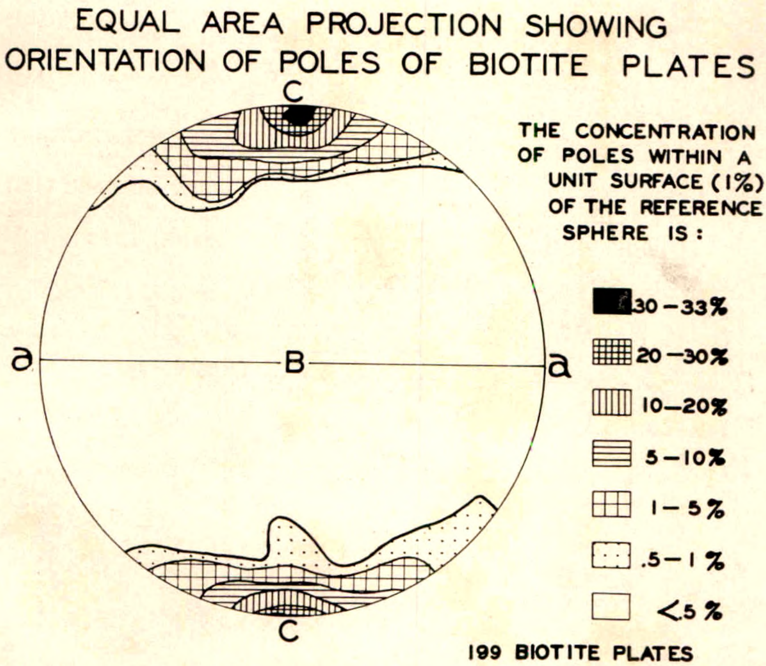


Fig. 2. Orientation diagram, biotite in biotite schist from near Albert Canyon Station, B. C.

be as rigorous as in crystal symmetry. The maximum concentration is 41½° from the schistosity.

There is, of course, a subjective element involved in the characterization of the symmetry of such diagrams, which, being statistical only, must be classified more or less arbitrarily.

Considering the biotite pattern of Fig. 2 alone, it is possible to class it as rhombic, with three planes of approximate symmetry. Indeed, the maxima of the quartz diagram of Fig. 3 approach a symmetrical disposition with respect to the *ab* and *bc* planes as well as the emphatic symmetry with respect to the *ac* plane. The diagrams have been classed by Sander[7] as

[7] Personal communication, May 2, 1933.

rhombic with monoclinic tendencies. My personal preference would be to interpret them as monoclinic, since actual measurement of the angles between the maxima and the *bc* or *ab* planes indicates rather considerable departures from symmetric disposition although a rhombic pattern is suggested.

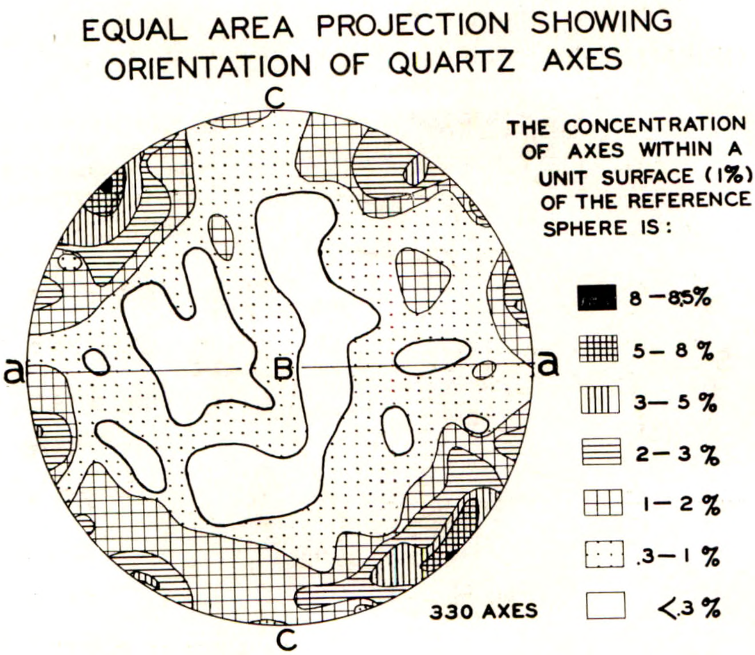


Fig. 3. Orientation diagram, quartz, in rock of Fig. 2.

The orientations of the biotite plates and quartz grains of the gneiss from Seymour Arm are shown in Figs. 4 and 5, respectively. Owing to an error in marking the rock for cutting, the section was not cut truly normal to the linear parallelism of the rock by about 9°. Although it is readily possible to rotate the diagrams by construction and correct this, it is thought that this rotation is not required to show the dominant features of the symmetry. The poorer orientation of the biotite plates of the gneiss as compared with those of the schist is clear. This is seen from the fact that concentrations nowhere exceed 12 per cent of the axes within 1 per cent of the area in Fig. 4, whereas in Fig. 2 they reach 30 per cent. It is also

evident from the marked elongation of the concentration greater than random expectancy in the *ac* plane (110° in Fig. 4 as compared to 70° in Fig. 2), and finally, from the smaller but pronounced elongation in the *bc* plane (70° in Fig. 4 as compared to 52° in Fig. 2). The *ac* girdle is almost

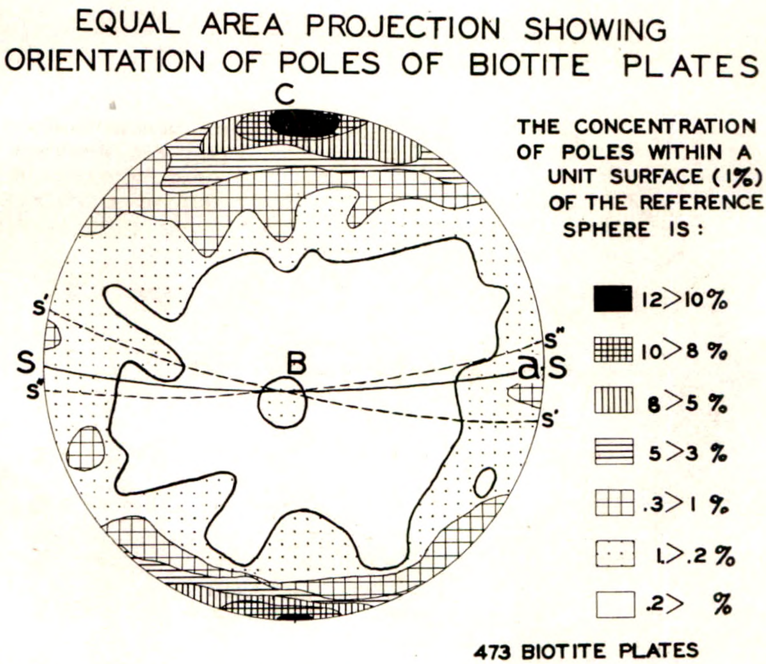


Fig. 4. Orientation diagram, biotite in biotite gneiss, Seymour Arm, Shuswap Lake, B. C.

two-thirds complete in Fig. 4. Part of this spread is due to the presence of several surfaces of schistosity in this rock intersecting at low angles, instead of a single schistosity as in the schist of Fig. 2. (See Fig. 1.) The most pronounced schistosity plane is indicated by the line S-B-S, two of the less prominent by s′-B-s′ and s″-B-s″. Incidentally, the *approximately equal* development of several surfaces of schistosity in a rock is incompatible with a theory that would explain the schistosity as a result of crystallization according to Riecke's principle, normal to the maximum pressure or in the plane of rock elongation.

Fig. 5 illustrates the quartz orientations. This, too, shows poorer order than is shown in the quartz diagram for the schist. The maximum concentration in Fig. 5 is less than 3.5 per cent, whereas that in Fig. 3 is 8.5 per cent. Furthermore, instead of forming a practically complete girdle normal to B there is a

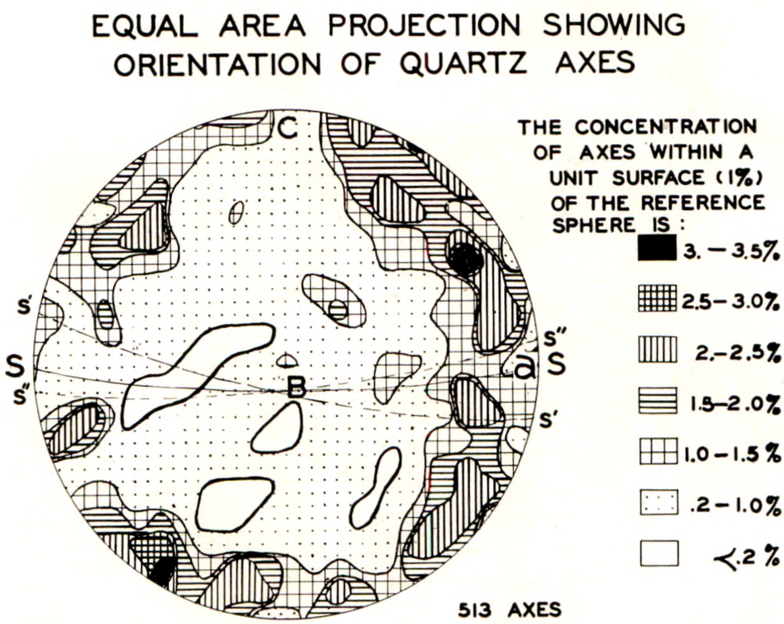
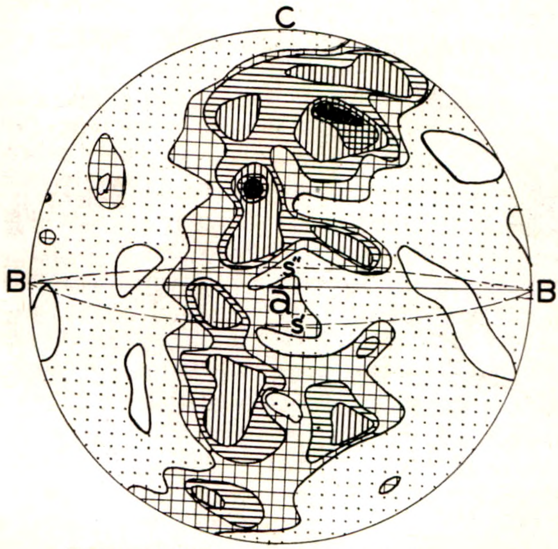


Fig. 5. Orientation diagram, quartz in biotite gneiss of Fig. 4.

much more irregular girdle, the major concentrations lying on either side of the *ac* plane. This is more clearly visible in Fig. 6, which embodies the same data as Fig. 5 but is rotated 90° about *c*. The crude suggestion of bilateral symmetry of the double girdle is apparent. The diagram is clearly triclinic, although it has a monoclinic habit, with a plane of approximate symmetry normal to B which marks the gneiss as a B-tectonite as well as the schist. The deviation from a real monoclinic symmetry may be due to one of several factors, such as superposition of a later movement at an angle to an earlier, or tectonic transport between walls of variable friction. Whatever the cause of the triclinic symmetry of the gneiss, it so nearly conforms with the monoclinic symmetry of the schist that the

two orientation patterns can reasonably be referred to a common cause.

The systematic distribution of these maxima is almost as important and as demonstrative of the dominance of a certain orienting mechanism in the rock as is a high percentage con-



FOR LEGEND SEE FIGURE 5

Fig. 6. Orientation diagram of Fig. 5, rotated 90° about the *c*-axis.

centration of axes within a limited area of the reference sphere. This fact must be considered as well as the mere percentage concentrations in evaluating the significance of oriented grain fabrics.

INTERPRETATION OF THE DIAGRAMS.

It is not the purpose of this paper to discuss in detail the mechanism producing the orientation of the quartz grains, although these problems are fundamental and of great interest and still largely open to argument.[8] However, the following points may be emphasized:

1. This girdle orientation is common and is the diagnostic character of a great class of metamorphic rocks, called the

[8] See especially Sander, B., op. cit., pp. 143-217, and Schmidt, W., Tektonik and Verformungslehre, pp. 171-203.

girdle or B-tectonites, which are widely distributed in the overthrust sheets of the Alps.

2. The symmetry of the diagrams, instead of conforming to a *normal* to the schistosity, conforms to a line *in* the schistosity. It may be pointed out that shearing normal to B in the plane of schistosity (or, of course, in any other plane embracing B) would set up rotational strains in the quartz grains with this girdle as the plane of deformation, as has been shown in the above-cited references both by Schmidt deductively and Sander inductively. In other words, rotational strain and torque on individual grains are to be expected in any penetrative movement involving tangential transport in which the line B(= b) marks the axis of rotation. Furthermore, shearing in the rock can hardly have been important along other planes than those of the schistosity without becoming apparent either in the textures of the rock or in the orientation diagrams. (See Sander's diagrams for many examples illustrating this.)

3. The diagrams strongly suggest rotation of the quartz grains in the plane normal to B. Since the crushing strength of quartz[9] parallel to c' is nearly 10 per cent greater than normal to c', it may be that this orientation is to be explained by the greater durability, during cataclastic deformation, of quartz grains that originally chanced to be oriented with their c-axes in the plane of rotation. Such grains would, during most of a revolution, present somewhat greater resistance to crushing than their random-oriented fellows. Hence they may be expected to survive, on the average, in somewhat larger individual grains than the others. When crystalloblastesis ensued, they would thus be favored in growth by their larger size, so that even in crystalloblastic textures they might be expected to dominate statistically over grains oriented at random and thereby to preserve a record of earlier shearing and cataclastic deformation. Another possible explanation for such a selection of grains oriented with their c-axes in a common plane is the assumption (for which there is considerable support, see Schmidt and Sander) that in each of the three planes of readiest gliding in quartz (the positive and negative rhombohedrons, r and z, and the hexagonal prism m)[10] the direction of readiest gliding is in the trace of a plane embracing the c-axis. Hence grains originally oriented with their

[9] Berndt, G., cited by Sosman, R. B., The properties of silica: Amer. Chem. Soc. Monograph Series, No. 37, p. 480, 1927.

[10] Sosman, R. B., Op. cit., p. 487.

c-axes in the plane of deformation would again be favored over their fellows, for they could accommodate themselves to deformation by gliding while the other grains would be breaking down.

Whatever the merits of these two hypotheses, the girdle-tectonites suggest strongly their formation during rotational movements of the component grains of the rock—and indeed penetrative differential movement down to the order of magnitude of the individual grains. The fact that the girdles are oriented normal to a line in the schistosity seems clearly to show that they are due to shearing; and that the shearing occurred in the plane of schistosity is highly probable for the reasons cited above. It seems to me that these diagrams furnish evidence that in these particular rocks, the *flow* cleavage occurs in the shearing planes and not in the plane of the major axes of the strain ellipsoid. It has, of course, long been recognized that in continued deformation the planes of shear may approach almost infinitely closely to the direction of rock elongation, although never actually coinciding with it.

One other point that seems to follow from the diagrams: The plane of deformation is normal to the linear element in the schistosity. Therefore, the linear elements in these rocks are not analogous to flow lines in igneous rocks. On the contrary, although there may have been some extension of the rock parallel to them, they represent very likely the intermediate axis of the strain ellipsoid and the intersections at low angles of shear planes along which the displacement has been normal to and not parallel to the linear elements. The occurrence of this type of linear element must be emphasized in view of the fortunately growing use of the methods of the Cloos school in structural studies of igneous rocks, as it necessitates caution in the too facile interpretation of linear parallelism as flow lines. It is necessary to demonstrate in each rock mass, especially in a metamorphic terrane, whether a given linear element is a relic of magmatic flow and lies in the direction parallel to which shearing has occurred, or whether, as in these rocks and most of the B-tectonites it lies normal to the direction of rock mass movement. This is not to deny that in many metamorphic rocks the linear parallelism lies in the direction of rock movement and that in B-tectonites there may be elongation parallel to B, but in each case this must be independently shown before making deductions as to rock movements.

Although it seems conclusive that the metamorphism of these

rocks is not static, it is not justifiable to conclude that load is thereby excluded as an important factor in bringing about the deformation recorded in the rocks. If we assume a column of rock of the necessary thickness (and with temperature gradient and solvents appropriate) to produce flowage simply by the superincumbent load, there must ordinarily be an extension of the lower layers in some horizontal direction because in many rocks, especially in those like the two studied, the density changes are relatively slight and if the rock mass is shortened vertically it must lengthen horizontally. The orientation of the girdles excludes the suggestion that mere elimination of original pore space accounts for the readjustment of the rock. These horizontal extensions must integrate into very large displacements if such conditions obtain over a considerable area, as in a geosyncline. The differential movements between rock particles as small as grains, such as are recorded in the diagrams, may each be slight, but their sum in a geosyncline area may mean a horizontal displacement of huge rock masses with respect to the basement. Only where escape is equally restricted in all directions would the differential movement be simply a resultant of superincumbent load. Everywhere else there must be tangential as well as radial movements in the rocks. The result may be large mass movements—whereby load metamorphism merges into dynamometamorphism.

In the broad outlines such a scheme is quite different from that given by the shearing of large masses through the operation of distal forces, yet within the rocks the differential movements might be entirely similar. So far as they go, however, it is believed that the orientation diagrams of Figs. 2 to 6 show that the movements within the units of the rock mass examined, and hence the actual processes operating during the metamorphism, were analogous to the penetrative differential movements recorded in many Alpine tectonites. Although load may have produced the movements in the rock, the actual crystalloblastic metamorphism was controlled not by the load, but by the movements. The recrystallization was governed by the conditions of penetrative movement and the metamorphism was dynamic.

In conclusion, the purpose of the present paper is not to present any general theory of metamorphic structures but merely to furnish an example of the methods recently developed by Schmidt and Sander for their study and to apply these

methods to a single terrane. The interpretations of the diagrams may, of course, require radical revision as studies proceed, but the application of these methods seems destined to contribute fundamental data to an eventual comprehensive theory of metamorphism.

The stimulating criticism of A. C. Spencer and other colleagues of the U. S. Geological Survey and of R. T. Chamberlin of the University of Chicago is gratefully acknowledged, without, of course, committing them to any of the opinions expressed. The writer is also indebted to Professor Sander for his cordial hospitality and many illuminating discussions of petrotectonics during a few weeks' visit to Innsbruck in 1932.

United States Geological Survey,
Washington, D. C.

THE SAN FRANCISCO MOUNTAINS METEORITE.

STUART H. PERRY.

The singularly beautiful siderite here described is of comparatively recent fall, is practically complete, and retains in perfection the structure of its fusion crust.

It was found by a Mexican sheep herder about 1920 on the lower northerly slopes of the San Francisco Mountains near Flagstaff, Arizona. The exact spot could not be identified. but it was described by the finder as being fairly level and barren save for scanty grass.

He took the iron to John Clark, now dead, at that time the proprietor of a store in Flagstaff. Mr. Clark at first suspected that it might be silver, perhaps because of the shining spots on the surface; later he concluded that it was of no value and gave it to John Marshall of Flagstaff, an elderly man employed at the city waterworks at the time the writer talked with him in 1928. Mr. Marshall cut off a small piece from the thicker end and sent it to an assayer, who advised him that the material was iron with a substantial percentage of nickel. Two or three small dents appear near that end, apparently caused by hammer blows.

The shape of the mass, which when obtained by the writer weighed 1,553 grams, suggests that of the forward half of a human foot, its length being about 8.5 cm. and its greatest thickness in either direction about 6 cm. When lying on its "sole" (as shown in Figure 1) the upper surface slopes away on each side from the central ridge to a rounded edge which retreats from the forward tip like the small toes of the foot. The larger end, originally bluntly rounded, now presents a flat cut surface about 5.5 by 4.5 cm. A very thin slice was removed by the writer from this end to obtain a suitable section, the fragment removed by the former owner having left an irregular surface.

Most of that fragment was recently found by H. H. Nininger of Denver in the form of a small slice weighing 60 grams. The slice is about 5 mm. thick and its larger surface is about 3.5 by 4 cm. On three sides the edges are square but the fourth side is sloping, which makes it possible to reconstruct the original form of that end of the mass. Figure 1 shows the shape of the larger end after restoring the two slices to approximately their original positions with plasticene.

The greatest thickness of the material lost could not have been more than 1.5 cm., and its weight could hardly have exceeded 100 grams. The total original length of the mass therefore may have been 10.5 to 11 cm. and its original weight about 1,700 grams.

The specific gravity, on an average of three slightly differing determinations, is 7. 87.

An analysis made by F. A. Gonyer of Harvard University gives the following composition:

Iron	91.91
Nickel	7.83
Cobalt	.16
Copper	.03
Insoluble	.03
	99.96

The insoluble residue when examined under the microscope was found to be ferric oxide. No trace of sulphur or phosphorus was found, though additional tests were made for those elements. The material used consisted of the sawings obtained when the thin slice was removed, which reflected fairly the average composition of the mass.

In the analysis the iron was converted to ferric sulphate, reduced and titrated with potassium permanganate. Nickel was precipitated and weighed as nickel glyoxime, the iron being held in solution with tartaric acid. Cobalt was determined as the sulphate after removing the iron and nickel, the former by three precipitations as ferric hydroxide and the latter by precipitation as nickel glyoxime. Copper was precipitated as the sulphide, converted to the sulphate and electrolyzed. For sulphur, precipitation as barium sulphate gave negative results. The same was true of the precipitation of phosphorus as ammonium phospho-molybdate, its conversion to magnesium ammonium phosphate and final weighing as the pyrophosphate. The absence of sulphur and phosphorus is consistent with the structure to be described later.

The most striking feature of the specimen is the fusion crust covering most of the exterior, well shown in Figure 2. Except for a few spots where the metal shows a shining surface, as though nickel-plated, the surface is covered with a hard, blue-black, somewhat lustrous scale- or slag-like coating of ferric oxide, which is generally of the thickness of heavy paper and is firmly adherent. Where the larger end was

Fig. 1. View of the mass showing approximately the original shape of the larger end. The portions removed have been restored to their positions with plasticene.

Fig. 2. Side of the mass showing striated fusion crust and cavities.

cut the crust in a few places is a millimeter thick, and at the smaller end it apparently is somewhat thicker.

Wherever the crust is intact it is marked by striations and fine ridges, which in places resemble hairs blown thickly across the surface, crossing one another. From the larger end, which obviously was forward in flight, the fused matter was swept backward toward the smaller end and around the rear edge—the "toes" of the foot—which is thereby thickened and rounded. A similar flowing took place around one of the lateral edges for its entire length. The effect is especially striking in such places, the fused matter having turned around the edges and produced the effect of a thick binding covered with the hair-like ridges.

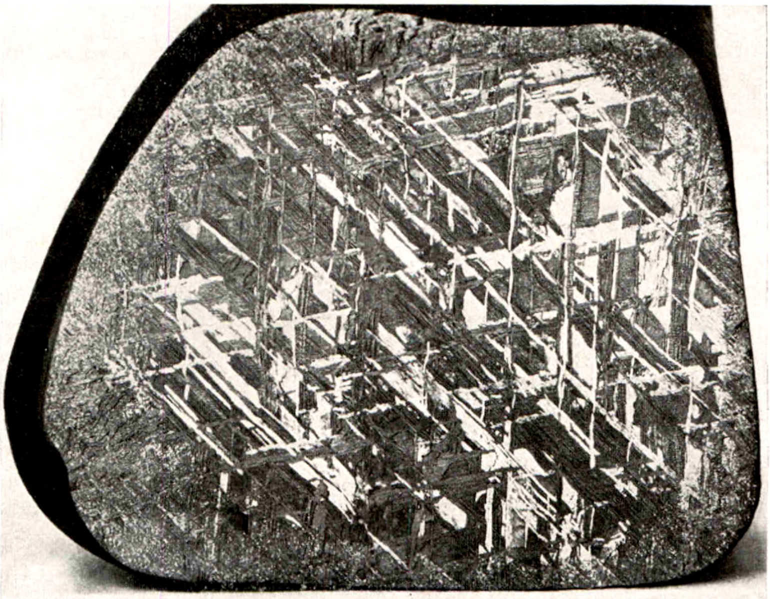
It is regrettable that the tip of the larger end with its striations was removed. Fortunately, however, the smaller end, where the surface structure is so perfectly developed has remained undisturbed.

Save for three or four small sharp depressions or cavities, the entire surface is even and bears no trace of the familiar pittings. In both respects, as well as in size, surface markings, internal structure and composition, this iron strongly resembles the Boogaldi iron, the small cavities on which were likened by Cohen to the blow-holes sometimes seen in artificial iron.

The mass was sawed without difficulty and the polished surface appears dense and homogeneous to the eye or under a magnifying glass, with no inclusions, fissures or marks of any kind. It etches readily, revealing a very fine octahedral structure in which all the members of the trias are characteristically developed. The structure is very distinct, the strong oriented sheen of the three sets of bands making a beautiful effect either to the eye or under the microscope (Figure 3). The section was made not far from a dodecahedral plane, giving a figuration of triangles and rhomboids with angles of around 55,55 and 70 degrees.

The Widmannstätten figures extend over the entire surface of the section with almost perfect uniformity, save for a zone of alteration around the periphery of the slice in which they are obscured though not obliterated.

No inclusions of troilite or schreibersite could be found. Under a metallographic microscope a micro-polished unetched surface showed a few rounded, slightly elongated, isotropic inclusions varying from 0.05 to 0.1 mm. in greatest diameter, which by their form and characteristic light purplish color are



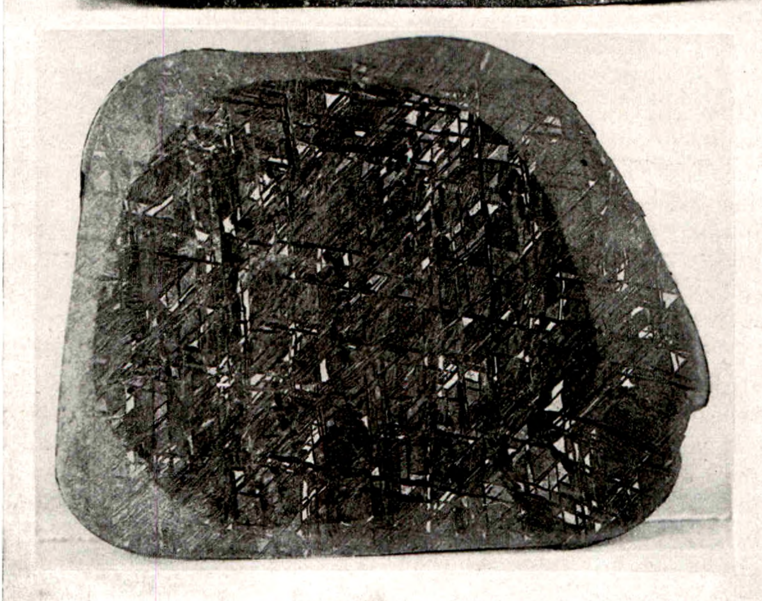


Fig. 3. End of mass, etched in the ordinary manner with 5% nitric acid in water.

Fig. 4. Micro-polished section showing zone of alteration. Etched with 3% nitric acid in alcohol, 35 seconds.

probably chromite, though no chromium was found in the analysis.

The kamacite bands are mostly from 0.1 to 0.15 mm. wide, many exactly of the former width. Sometimes they are even narrower, while a few are 0.2 or 0.25 mm. wide. Some bands vary irregularly, but most of them hold their width quite uniformly at almost exactly 0.1 mm. A few short swollen bands attain a width of 0.3 mm. Much of the kamacite is grouped irregularly, in fascicles of a width up to half a dozen bands. Though the general effect of the figures is regular and uniform, under the microscope the bands are more or less wavy, and in places appear twisted and interwoven in a pattern suggesting basketwork, some of them short with rounded ends.

Many of the bands are as long as 3 or 4 cm. and are fairly continuous across the entire area within the zone of alteration, and in some places extending visibly through it to the extreme edge of the section. With the light in one direction, only long and narrow bands are visible to the eye by their sheen; in the other two directions the bands are grouped in conspicuous strips.

Practically all the kamacite is hatched with Neumann lines (the schraffierter Kamazit of the German writers) and with ordinary macro-etching under a magnification of 100 diameters they show a uniform mat surface. On a micro-polished surface, after successive etchings, the unaltered kamacite reveals no structure save for the development of abundant Neumann lines.

Coarsely granular (abkekörnt) kamacite is common in the light plessite fields, to be referred to later.

Practically all the kamacite, both in bands and fields, has a strong oriented sheen. Three orientations with reference to the source of light, approximately 90 degrees apart, thus bring out certain portions brilliantly. In a fascicle of grouped bands the sheen is likely to be uniform in all the bands, especially if they are not clearly and effectively separated from one another by continuous taenite lamellae. The same uniformity is observable in a few rounded kamacite areas in which the taenite appears as irregular inclusions. Often different parallel grouped bands respond differently to the light, one band remaining dark between two bright ones, or vice versa. In such cases the contrasting bands are usually, though not invariably, regular in form and bounded by distinct and continuous taenite lamellae.

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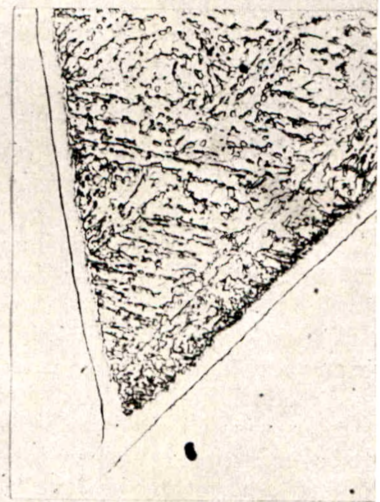

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Fig. 5. Kamacite band between two light granular fields. x 100 (3% nitric acid in alcohol, 15 seconds).

Fig. 6. Light granular field with taenite particles. x 100 (5% picric acid, 4 minutes).

Fig. 7. Coarsely granular field with incipient bands. x 100 (5% picric acid, 4 minutes).

Fig. 8. Micro-plessite, part of black triangle in Fig. 9. x 1000 (5% picric acid, 3 minutes).

These observations are consistent with the conclusion of Osmond and Cartaud, developed by later writers, notably Benedicks,[1] that if a low-nickel iron alloy cools slowly enough to permit the gamma-alpha inversion at about 400 C. the result is hexahedral alpha-iron; although the Widmannstätten structure produced by crystallization in the gamma (octahedral) stage remains as an alpha pseudomorph of the original gamma iron. Thus complete transformation of the kamacite into the hexahedral phase would presumably produce identical crystallographic planes throughout any given kamacite mass or plate, or throughout a group of plates if they were not completely separated by taenite films (the taenite having been rejected previous to the gamma-alpha inversion) the result being a uniform sheen. If certain plates, however, were effectively isolated from their neighbors by continuous taenite layers, their crystallographic planes in the new phase might not be identical.

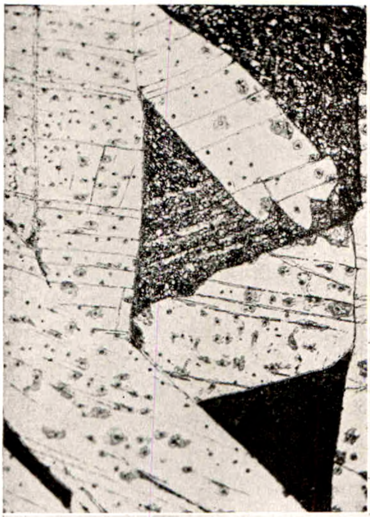
Of course it is impossible to be sure that a given plate is thus isolated throughout its extent, because the bounding walls of taenite appearing in a polished section may not be continuous, and somewhere below the surface the apparently discrete plates of kamacite may coalesce.

Taenite is abundantly and uniformly distributed, running to the extreme edges of the section and up to the line of contact between the iron and the fusion crust. It occurs as tenuous lamellae bounding the kamacite plates, as well as in the form of particles sprinkling some of the eutectoid fields. No example of skeletal growths (Kämme) within plessite fields was observed.

The taenite films, though abundant, are so thin that they are not visible to the eye upon an ordinary etched surface. Upon a brief application of very dilute nitric acid (5% in water)—and still more so on light etching with mercuric chloride—the fine brilliant lines are brought out conspicuously. Not only is the octahedral structure thus outlined to the naked eye, but under a hand glass the taenite also appears in innumerable particles or spicules, the lighter fields presenting a shimmer of minute silvery points. The brilliant effect of the chloride etching is due in part to the lodgment of microscopic globules of mercury.

In addition to its regular distribution, the taenite also occurs as relatively thick lines in arborescent or sprangly forms,

[1] Synthèse du Fer Météorique. Nova Acta R. S. S. Upsaliensis, Ser. IV, Vol. 2 (1910).



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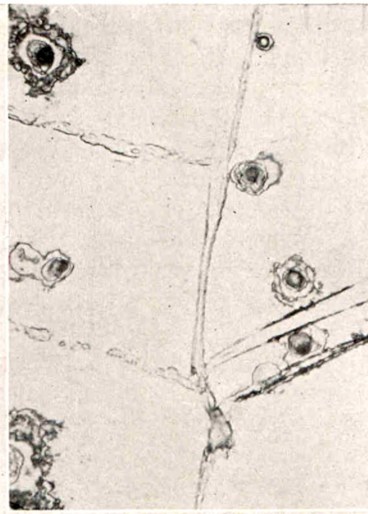

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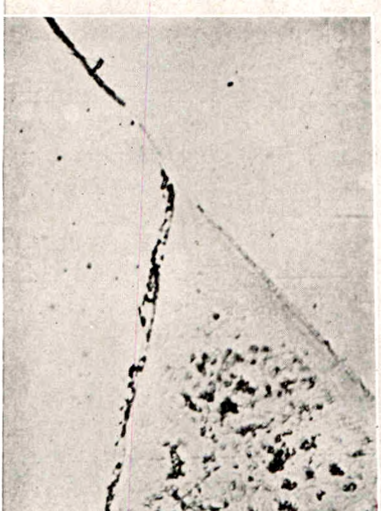

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Fig. 9. Etching pits in kamacite. x 100 (3% HNO_3, 35 seconds and ferric chloride 10 seconds).

Fig. 10. The same. x 1000.

Fig. 11. Part of area shown in Fig. 8. x 1000 (boiling sodium picrate, 30 minutes).

Fig. 12. Slightly altered kamacite, inner part of zone. x 100 (3% HNO_3, 25 seconds).

invading the octahedral structure but without disturbing its visible regularity. Under the microscope they are seen to inclose in places comparatively large, irregularly rounded areas of kamacite, homogeneous, usually hatched with Neumann lines, and brilliant in sheen. The trend of these growths is roughly parallel across the slice, several of them extending across the altered zone and some reaching the extreme edge.

Plessite fields are abundant, occupying perhaps half the area of a polished section. Light fields—the macro-plessite of Pfann—are most numerous and largest, reaching dimensions of from 3 to 5 mm. The lighter fields are of three characteristic types:

1. Clear, coarsely granular fields; the grains, with numerous rounded drop-like particles of taenite at the junction of grain boundaries, coming out clearly on the lightest etching (10 seconds, 3% HNO_3). The appearance of such areas recalls the structure observable in hypo-eutectoid steels of moderate carbon content (Figure 5).

2. Similarly coarsely granulated areas filled with minute particles or spicules of taenite, often diversely oriented in the various grains (Figure 6).

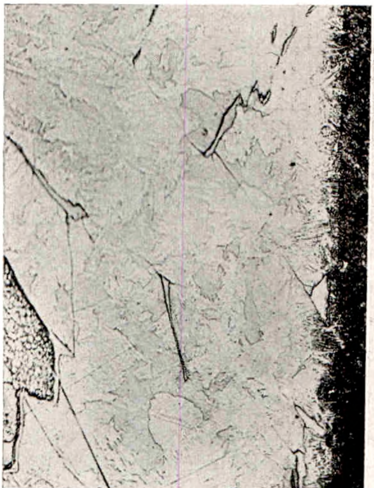
3. Fields showing a fairly coarse eutectiform granulation, the size, arrangement or separation of the grains often producing bands parallel with the planes of the octahedral structure (Figure 9).

In Figure 7, showing a field of the first type, an incipient kamacite band is in process of formation through the development of taenite lamellae.

In the first stage of etching the Neumann lines, which begin to show in the kamacite bands, do not appear in the granular fields, but on further etching they appear plainly, with more or less varying orientation. (See Figure 6.)

The kamacite in light fields usually shows an oriented sheen identical with that of the bands. The sheen is generally uniform in such areas; sometimes, however, the grains show some variation in brightness, though never in the orientation of the sheen. A few fields are dull, or show only a faint sheen, in all lights.

Dark plessite fields—the micro-plessite of Pfann—are less numerous, the complete section showing from 50 to 75. They are mostly very small, the largest observed being one of rhomboidal shape 0.8 mm. in length. Excepting some in the form of thin bands or baguettes between kamacite bands, they are



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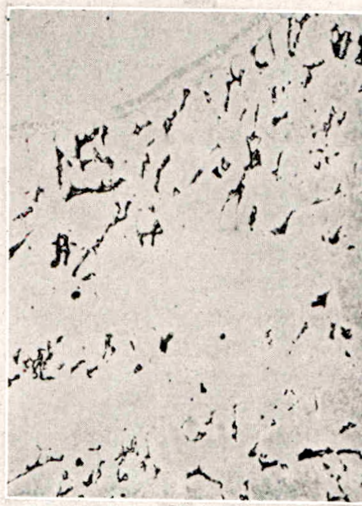

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Fig. 13. Altered kamacite adjacent to crust. x 100 (5% picric acid, 4 minutes).

Fig. 14. Altered and (at top) unaltered kamacite. x 100 (5% picric acid, 3 minutes).

Fig. 15. Neumann lines merging into new grain boundaries. x 100 (5% picric acid, 4 minutes).

Fig. 16. Part of the lighter banded triangle shown in Figure 9. x 1000 (boiling sodium picrate, 30 minutes).

usually regular in form and bounded by relatively thick taenite lamellae. Few strings or other irregular eutectoid remnants were observed.

Dark plessite fields are depressed by long etching, and on ordinary microscopic examination they appear dense and amorphous, though occasionally showing lighter bands. Under a metallographic microscope at 500 diameters they still show only an obscure granular structure, but 1,000 diameters brings out clearly the taenite particles interspersed in the ground mass, as shown in Figure 8. In this example there is a distinct orientation. In other fields the particles are irregularly scattered, the appearance being similar to that of the rounded cementite granules in a spheroidized eutectoid steel.

This structure is consistent with the statements of Vogel[2] who considers dark plessite to be a limited, dense-ataxite structure dependent upon a slight local phosphorus enrichment. The sharp segregation of the taenite parallels that observed in artificial nickel-iron alloys of similar proportions in which, according to Vogel, a very slight phosphorus content—as little as a few tenths of one per cent—produces a sharp separation of taenite, whereas in an alloy wholly free from phosphorus the separation is more or less indefinite. Such a local enrichment might easily exist without yielding any reaction for phosphorus in the analysis.

That such is the case in this instance, despite the absence of phosphorus in the analysis, is proved by etching with boiling neutral sodium picrate, which causes phosphides to turn black but has no visible effect upon the phosphorus-free taenite and kamacite. Figure 11 shows the effect of such etching on a part of the area in Figure 8 (which is a portion of the black triangle in Figure 9), revealing traces of phosphide in one of the taenite borders and minute segregations scattered in the interior. A portion of the lighter banded triangle in Figure 9, similarly etched, is shown in Figure 16.

Most reagents (except picric acid) quickly make cup-shaped etching pits large enough to catch a needle point, similar to those observed on the Charcas iron by Brezina[3] and on the Rodeo iron by Farrington.[4] The former suggested that they might be caused by minute inclusions of troilite, while the lat-

[2] Über die Strukturformen des Meteoreisens. Archiv für das Eisenhüttenwesen, I Jahrgang, Heft 9 (1928).
[3] Wiener Sammlung 275 (1895).
[4] The Rodeo Meteorite 2 (1905).

ter regarded them as more probably due to points containing less nickel than the surrounding mass and therefore more soluble. That they are not due to troilite inclusions is indicated by the fact that the pits are developed quickly by mercuric chloride, which does not attack troilite. An examination of an unetched micro-polished section at 1,000 diameters with polarized light failed to disclose any anisotropic inclusions; if there were any grains of troilite, which is hexagonal in crystallization, they should have shown extinctions.

The pits are scattered quite uniformly and appear to be independent of Neumann lines and of grain boundaries. They are often in contact with, though never in, taenite. (See Figures 9 and 10.) They are equally numerous in the bands and in the light fields, and this is true in the inner portion of the zone of alteration. They do not, however, appear in the outer part of the zone near the fusion crust. The pits are irregular, none showing any relationship with crystallographic planes. In that respect they differ from the ordinary etching pits of artificial irons, which often show cubic forms. Their relatively large size and quick development apparently are unusual in meteoric irons.

Applying copper ammonium chloride sufficient to give the slightest deposit of copper, most of the pits appear as dark spots in the faint flush of copper-red, each surrounded by an irregular silvery ring or aureole, which might suggest the presence of points of relatively lower nickel content. The disappearance of such points by diffusion under heat might account for the absence of the pits in the peripheral part of the zone of alteration.

This iron exhibits such a zone in great perfection. That feature, not common in meteoric irons, was first described by Reichenbach in the Braunau iron in 1862, and even as late as 1922 it was referred to by Merrill[5] as having been observed by him only in the Charlotte and Signal Mountain meteorites.

The zone, shown in Figure 4, appears to the eye as a distinct band of duller lustre extending inward to a width of from 2.5 mm. to a maximum of 1 cm. The line of demarcation between the altered and unaltered structures is very distinct—as is the case when a bar of coarsely crystalline steel is heated at one end above the critical temperature.

[5] Proc. U. S. Nat. Museum 61, Article 4 (1922).

In the zone the characteristic figures mostly disappear to the eye, though still observable in some places. Under the microscope, or even with a hand glass, the kamacite bands and their bounding lines of taenite can be traced everywhere without interruption, even to the line of contact with the crust.

This metabolite structure, exhaustively investigated by Berwerth and later by others, has been produced artificially in various experiments with octahedral meteoric irons. Berwerth by heating a piece of Toluca to 950 C. for seven hours produced a structure which he describes in words that would apply exactly to the zone of alteration in this case. He writes:[6]

> In place of the former dull or shining bands of the octahedral network, the etched surface of the annealed iron now presents a confused, sparkling, changeable sheen of grains. The form of the grains is not rounded; they seem rather to have somewhat of a flaky character, and appear like shreds giving off a changing sparkle like snowflakes on a roof. Microscopical examination shows that in reality they are not true iron grains, but shreds indenting one another in angular shapes as though one had bitten into another.

Figure 12 shows grouped kamacite in the inner part of the zone lightly etched (3% HNO_3, 25 seconds). The Neumann lines have disappeared and a ragged structure has started to develop, occasionally interrupting the taenite lamellae. This is the beginning of the change described by Berwerth in the passage quoted.

Nearer the surface of the mass the change increases (Figure 13) until at some points on the extreme edge it is fully completed.

The greater completeness of the transformation near the surface of the mass is also reflected in the absence of etching pits after longer etching, though with the same treatment they developed abundantly in the area shown in Figure 12.

Generally the beginning of the zone is marked by the abrupt disappearance of Neumann lines, as shown in Figure 14. In some places the development of the new granular structure apparently begins with the enlargement and distortion of the Neumann lines, closely parallelling the similar process described by Krivobok as the result of annealing samples of iron and

[6] Künstlicher Metabolit, Kais. Ak. Wiss. (Wien.) Vol. 114, Part 1, 343.

silicon-iron in which the lines had been produced by cold working.[7] This peculiar effect is shown in Figure 15.

Finely granular plessite areas show little or no alteration by diffusion. Coarsely granular fields similar to the one shown in Figure 6 are unchanged save for the disappearance of the Neumann lines. This would indicate that the temperature to which the superficial portion of the mass was subjected during its flight must have been of short duration and not excessively high.

The minimum temperature and time requisite for the complete alteration of kamacite were determined by Berwerth and Tammann[8] by a series of experiments on the Toluca iron. It was found that with annealing at 820 degrees for 20 seconds, or at 700 degrees even as long as 240 seconds, the alteration was incomplete; but that it was complete when the iron was subjected to a heat of 1,100 degrees for two seconds or 1,200 degrees for one second. Similar experiments conducted more recently by Tutom Kase on fragments of the Sacramento Mountain iron[9] established that when it is heated to 1,100 degrees, kept there "a moment" and quenched in water, the micro-plessite areas become homogeneous by diffusion, and that when heated to 1,200, kept there three minutes and quenched in water, the taenite bands are more or less dispersed by diffusion.

It would appear, therefore, that the outer portion of the iron here described could not have been subjected to more than the equivalent of one second's heating at 1,050, which Berwerth and Tammann concluded is the minimum for the complete alteration of kamacite. That equivalent obviously might be obtained at a somewhat lower temperature continued during a flight of several seconds through the air. On the other hand Berwerth and Tammann found that a temperature of 876 degrees continued for five seconds produced no substantial alteration. The record of their experiments does not indicate whether the samples were quenched or air-cooled.

Altogether it might be a fair conclusion in this case that the

[7] A Photomicrographic Study of Recrystallization in Certain Cold Worked Metals; Ann. Inst. of Min. and Met. Eng. Pamphlet 1557; summarized with illustrations by Sauveur, The Metallography and Heat Treatment of Iron and Steel (Third ed.), 277-283.

[8] Über die natürliche u. künstliche Brandzone der Meteoreisen. Zeits. f. Anorg. Chemie Bd. 75, p. 145 (1912).

[9] The W. Structure in Iron-Carbon and Iron-Nickel Alloys and Meteorites. Science Rep., Tohoku Imp. Univ., Vol. 14, 537 (1925).

outer portion may have been heated for several seconds to a temperature around 1,000 degrees and quickly cooled, the effect of the extremely cold interior having been somewhat that of quenching.

Whether it be assumed that the Neumann lines are due to mechanical twinning caused by shock or stress below the point of the gamma-alpha inversion, or, on the analogy of artificial nickel-iron alloys, that they arise in the gamma range and are preserved by quick cooling into the alpha range, in either case they would be destroyed and a granular structure produced by re-heating within the limits of the alpha range, whether followed again by quick or by slow cooling. If the heating of the iron in its passage through the air extended far into the gama range, then—on the analogy of artificial alloys—quick cooling might have preserved the Neumann lines of the gamma structure. Such, however, was not the result.

It seems likely, therefore, that the zone was not heated very far above the point of the alpha-gamma inversion. With the nickel content of kamacite this point (on heating) would be around 700 degrees. That conclusion would be consistent with the results of the experiments before referred to, and also with the slight depth of the alteration. If Neumann lines are produced by stress or shock below the critical temperature, the impact of the meteorite upon the earth might have produced them in the cold interior, but not in the zone of alteration which when the mass reached the earth must still have remained at a temperature above the critical point—that point, for such an alloy, being about 200 degrees lower on cooling than on heating.

The crust, though taking a high polish, is somewhat porous and shows a number of layers or bands. At one point, where it reaches a maximum thickness of about a millimeter, eight or ten such bands are distinguishable.

In this connection a brief comparison of the Charlotte and Boogaldi irons, which this one so much resembles, is of interest.

According to Cohen's description,[10] Charlotte shows a finely striated crust. Kamacite bands about 0.17 mm. wide, with a delicate sheen, strongly grouped, predominantly hatched, partly granular. Fields form nearly half the surface, dull or shimmering, some containing skeletal taenite growths (Kämme); few dark plessite fields. Taenite conspicuous, on

[10] Meteoritenkunde III, 320, 390.

one section appearing in a strongly wavering or zigzag course. Granular flecked zone of alteration 3.2 to 3.4 mm. thick. The presence of troilite is noted, though the analysis shows no sulphur.

Boogaldi shows a fusion crust and surface structure very similar to those of the iron here described, with shining spots and small cavities like blow-holes. Kamacite bands very long, usually straight, not swollen, mostly strongly grouped, abundantly hatched, with strong sheen; a few granular. Plessite strong, uniformly distributed, of the several types noted in the iron here described; some with skeletal taenite. Taenite clear but weakly developed. No zone of alteration.

The analyses show 8.05% of nickel in Charlotte and 8.01 in Boogaldi, as compared with 7.83 in the iron here described. Like it, they both contain fractional percentages of cobalt and copper, with no sulphur or phosphorus. Both are placed by Cohen in the Prambanan group of fine octahedrites (OfP). According to the accepted classification, based on the width of the bands, this iron clearly belongs in the comparatively small class of finest octahedrites (Off). Within that class it would be placed in the Salt River group according to Cohen's classification, although the percentage of nickel is lower than in any of the irons of that group, and although phosphorus, which appears in all analyses of the finest, and of nearly all the fine, octahedrites, is not chemically discoverable.

Owing to the lack of data justifying a more specific local designation, the name San Francisco Mountains is chosen for this meteorite.

ADRIAN, MICHIGAN.

AN INVESTIGATION OF THE LIGHT-COLORED, CROSS-BEDDED SANDSTONES OF CANYON DE CHELLY, ARIZONA.

EDWIN D. MC KEE.*

PURPOSE AND ACKNOWLEDGMENTS.

During the week of Nov. 5-12, 1932, the writer made detailed studies of the light-colored, cross-bedded sandstones of the Canyon de Chelly region of northeastern Arizona in an attempt (1) to determine whether a relationship exists between those cross-bedded sandstones and the Permian Coconino sandstone of the Grand Canyon region, and (2) to obtain as much information as possible relative to the origin and history of those sandstones, especially as they are found in the walls of Canyon de Chelly and Canyon del Muerto. The work was done under a grant from the Carnegie Institution of Washington and by direction of the Director of the National Park Service.

WORK OF PREVIOUS INVESTIGATORS.

The brilliant red, cliff-forming sandstones of the Canyon de Chelly region were noted many years ago by various geologists, all of whom considered them to be the equivalent of the Vermilion Cliff or Wingate sandstones of Mesozoic age. In 1917, Dr. Herbert E. Gregory[1] properly assigned them to the Permian age because of their stratigraphic position unconformably beneath the Shinarump conglomerate (Triassic) and conformably above red beds containing a Permian flora. To these sandstones he gave the name De Chelly. Because of their extensive cross-bedding, cliff-forming nature and stratigraphic position, they have since been considered by Darton[2] and by Baker and Reeside[3] to be a continuation of the Coconino sandstone found to the west and southwest. All of these writers believed the De Chelly to be continuous into the Monument Valley region to the north, although Baker and Reeside have included under this name only the upper cross-bedded sandstones of that area, considering the lower ones to be a southern extension of the Cedar Mesa sandstone.

* Park Naturalist, Grand Canyon National Park.

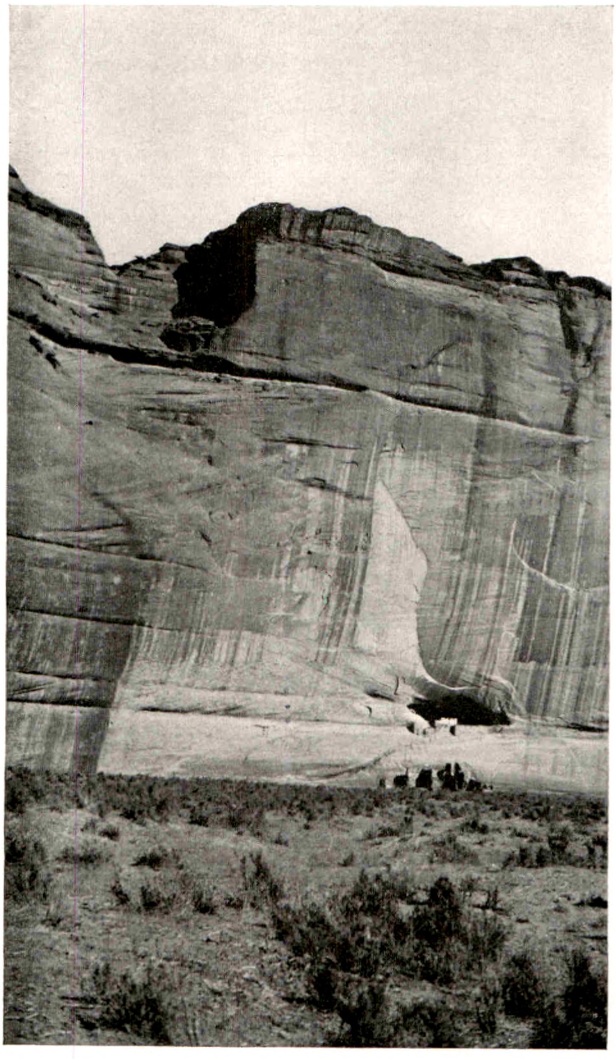

Fig. 1. Canyon de Chelly at White House. Only the upper member of the De Chelly sandstone is exposed here. Note repeated units of long parallel, sloping laminae.

UNDERLYING RED BEDS.

Eastward from near where Monument Canyon joins Canyon de Chelly the lower walls of both canyons are composed of brick-red sandy shales and fine-grained sandstones which have been called Moencopi by Gregory,[4] Supai by Hager[5] and by Darton[6], and a tongue of the Cutler formation

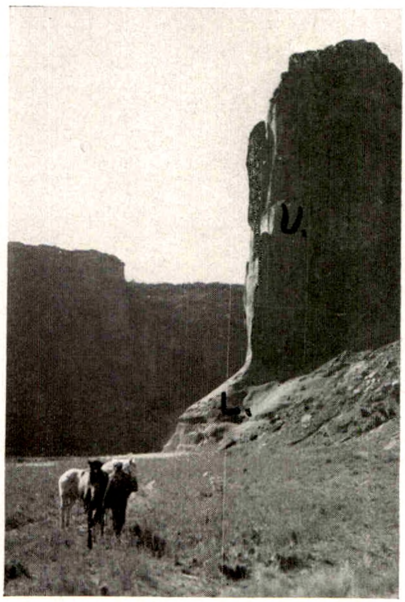

Fig. 2. Contrasting profiles of upper and lower members of De Chelly sandstone.

by Baker and Reeside[7]. The lithologic character of these rocks is much like that of the Supai formation of Grand Canyon. Fossil plants have been found in them three miles west of Fort Defiance and determined by David White[8] to be Permian. At least one of these (Walchia piniformis) is found also in the Hermit shale of Grand Canyon.

DESCRIPTION OF SANDSTONE IN CANYON DE CHELLY.

Conformably above the red beds occur the vermilion cross-bedded sandstones which form the major part of the walls of Canyon de Chelly and extend within a few feet of the

top where apparently they are everywhere capped by horizontal ledges of Shinarump conglomerate. Throughout that part of the canyon where their entire thickness is exposed, the cross-bedded sandstones appear to form two distinct and well-defined units separated by some horizontally bedded layers of very fine-grained, red, argillaceous sandstone. In color, type of cross-bedding and erosional behavior, the upper and lower sandstones may be readily distinguished, but in mineral composition they are similar in most places. The

Fig. 3. Walls of Canyon de Chelly showing contrast in weathering of upper (U) and lower (L) members of De Chelly sandstone.

upper member forms a smooth, straight wall of bright red color, often covered with black desert varnish. The lower member is reddish brown in color and usually weathers into rounded slopes containing many alcoves and cavities. In a few places it forms sheer cliffs and with the upper member makes one continuous perpendicular wall from bottom to top of the canyon. Even in these localities, however, the members may be readily distinguished by one or more of the characteristics mentioned above.

The cross-bedding in the lower part of the formation dips in nearly every direction with one curving wedge truncating another. In the upper member the beds are much longer and form in profile a series of nearly parallel sloping lines which curve only at the lower ends where the angles decrease as they merge into layers of non-cross-bedded shaly sand below. Such units of sloping beds with basal flat-lying beds are

repeated from twelve to twenty times to make up the cliff face of the upper canyon walls, and since the direction of dip in the sloping beds is remarkably constant—ranging from

Fig. 4a.

Fig. 4b.

Figs. 4a. and 4b. Unconformity between Shinarump conglomerate and De Chelly sandstone. Upper walls of Canyon de Chelly.

southwest to southeast—the appearance in profile views is that of a series of similar structures. No exceptions could be found to the general direction of dip, thus suggesting that the sediments of the upper member were transported from the north.

A section measured near the mouth of Monument Canyon is as follows:

Shinarump conglomerate
Unconformity

De Chelly sandstone	Feet
1. Sandstone, fine-grained: Vermilion red, cliff-forming. Cross-bedded. Composed in vertical section of a series of similar units, each with long, sloping, nearly parallel laminae which curve at their bases tangential to flat-lying, brown, shaly sandstone layers 6″ to 3′ thick, that separate the units. Twelve to twenty units ranging in thickness from four to eighty feet constitute this member. Sand grains of two sizes	569.5
2. Sandstone, argillaceous: Deep red, very fine-grained, non-cross-bedded. Rests on truncated surface of underlying sandstone. Some traces of sand of type found in upper and lower members	36.0
3. Sandstone, fine-grained: Red-brown, weathers to rounded surfaces. Cross-bedded with short curving surfaces forming irregular wedges, truncated at bases. Sand grains of two sizes	219.0
	824.5

Red Permian shales and flat-lying beds of sandstone.

The sand grains in both upper and lower members of the De Chelly sandstone appear to be consistently of two sizes as already pointed out by Gregory. This was found to be true wherever the formation was examined in Canyon de Chelly, and, moreover, in certain parts of it, surfaces of the coarser-sized grains appear to determine the bedding planes since the finer material forms the bottom sides of covering layers. The larger-sized grains of the De Chelly sandstone have diameters which are considerably greater than those of the sand grains found throughout the northern part of the Coconino formation, but the smaller ones average only slightly larger than those of the Coconino.

	Average
De Chelly sand grains (large)	.6 mm.
De Chelly sand grains (small)	.19 mm.
Coconino (northern part) sand grains	.21 mm.

Gregory mentions also "occasional scattered pebbles, one-sixteenth to one-eighth inch in diameter" in the De Chelly, but the writer did not find any of these.

The sand grains of the De Chelly sandstone are rounded in shape and composed of white quartz, red quartz and kaolin. Occasional mica flakes are present. The white quartz and the kaolin are found throughout the formation both in Canyon

de Chelly and in the canyons where it occurs to the south. Since kaolin is of a negligible amount in the true Coconino sandstone, its presence or absence in a sand sample makes an excellent criterion of relationship. Red quartz grains are

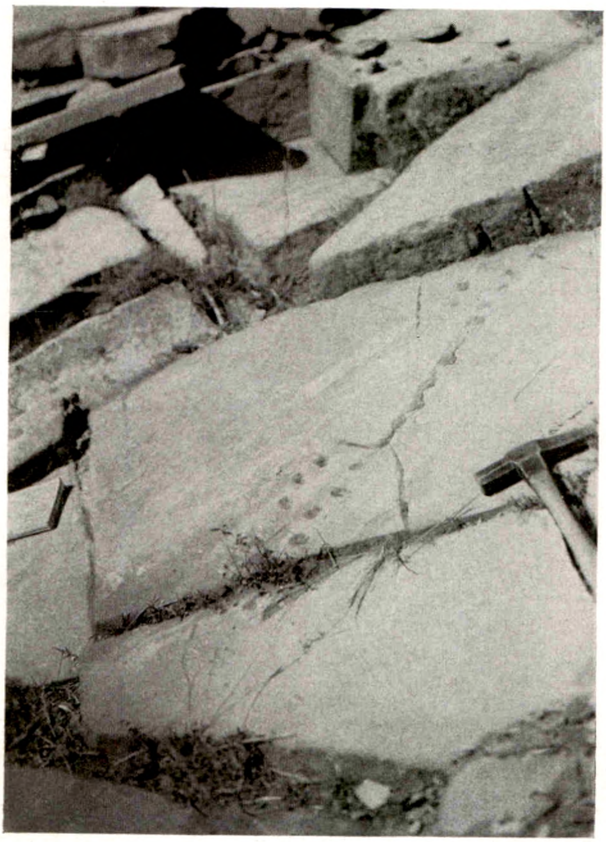

Fig. 5. Fossil footprints in Coconino sandstone, Kin-la-Chee Canyon.

especially numerous in the lower member of the De Chelly sandstone and are found throughout most of the upper part. In some places near the top of that member, however, they are absent and they are unknown from the true Coconino sandstone. The cement in the De Chelly is both iron and lime. The characteristics of this sandstone, therefore, seem to be fairly definite and consistent, and so permit it to be recognized

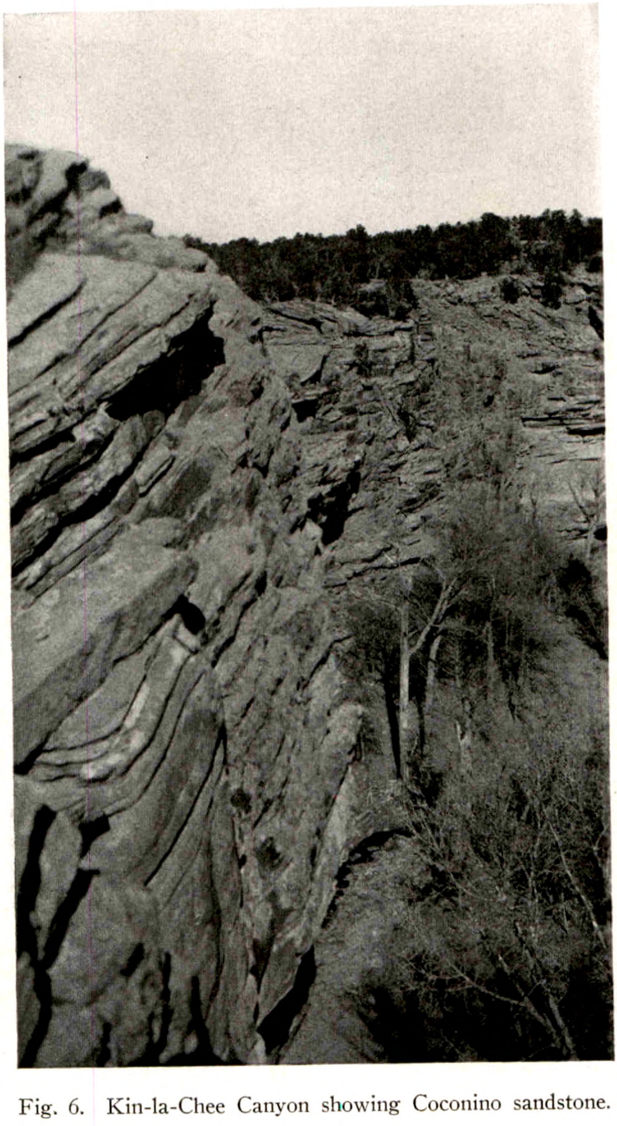

Fig. 6. Kin-la-Chee Canyon showing Coconino sandstone.

in other areas. A table contrasting these criteria with those of the type Coconino sandstone is given below:

	De Chelly Sandstone	Coconino Sandstone
Grain size	Fine, two sizes	Fine, remarkably uniform
Minerals	White quartz, red quartz, kaolin	White quartz
Cement	Iron, calcareous	Siliceous

SANDSTONES AT KIN-LA-CHEE CANYON.

At Kin-la-Chee Canyon, thirty miles south of Canyon de Chelly, was found about one hundred and fifty feet of white, cross-bedded sandstone. The bottom of this formation was not exposed and the top lay unconformably beneath the Triassic Shinarump conglomerate; hence it was impossible to determine its entire thickness.

The sandstone at Kin-la-Chee Canyon was found to resemble the Coconino in every essential—type of cross-bedding, color, grain size, mineral content, and cement. In it, furthermore, were found numerous tracks of vertebrate and invertebrate animals similar to those found in the Coconino sandstone of Grand Canyon. A slab was collected with the peculiar footprints of *Dolichopodus tetradactylus* Gilmore on it (Fco-30) and numerous specimens of *Laoporus noblei* Lull—the commonest species represented at Grand Canyon—were obtained. The measurements of three of these are as follows:

Fco-33			
Stride	70 mm.	Manus width	20 mm.
Trackway	50 mm.	Manus length	20 mm.
Pes width	22 mm.	No. Toes Pes	4 ?
Pes length	22 mm.	No. Toes Manus	4
Fco-36			
Stride	80 mm.	Manus width	17 mm.
Trackway	..	Manus length	17 mm.
Pes width	25 mm.	No. Toes Pes	5
Pes length	25 mm.	No. Toes Manus	4
Fco-32			
Stride	70 mm.	Manus width	20 mm.
Trackway	50 mm.	Manus length	20 mm.
Pes width	25 mm.	No. Toes Pes	..
Pes length	25 mm.	No. Toes Manus	..

Footprints of other species of vertebrates were seen in this locality and although specimens or measurements were not

taken, the writer feels reasonably certain that *Laoporus schucherti* Lull and *Baropezia eakini* Gilmore, well-known Coconino forms, were among them.

It should be mentioned that in certain limited horizons, both above and below those of the fossil footprints, were found sandstone slabs resembling in color, grain size and mineral

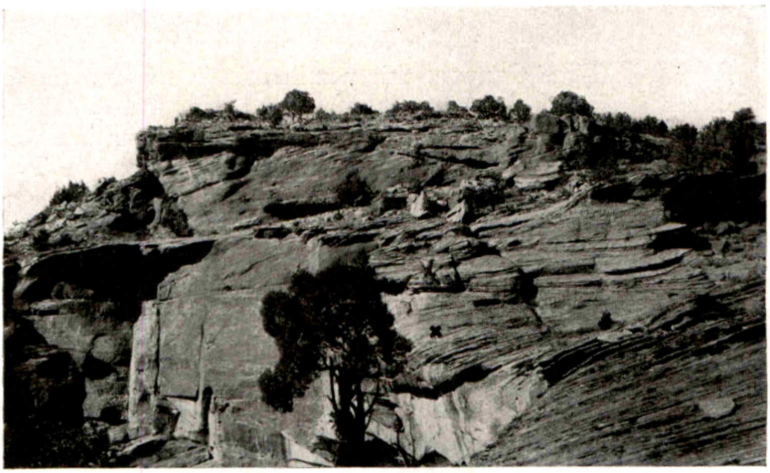

Fig. 7. Horizon of fossil footprints, Nazlini Canyon, Arizona. (Note ledge of Shinarump at top of picture.)

content the De Chelly sandstone. Despite their presence the writer considers that the main part of the formation probably represents a northeasterly extension of the Coconino sandstone as found near Holbrook, Arizona.

SANDSTONE EAST OF KIN-LA-CHEE.

The Coconino sandstone of the Kin-la-Chee was traced horizontally eastward across the Defiance uplift by means of exposures found near the Ganado-St. Michaels road. Samples collected at about two-mile intervals showed no appreciable change in character, nor did they differ materially from the Coconino of Grand Canyon. In most places they were unconformably overlain by Shinarump conglomerate.

SANDSTONE OF BONITO CANYON, FORT DEFIANCE.

At Bonito Canyon on the east side of the Defiance uplift, 263 feet of sandstones which are mostly cross-bedded, have been measured by K. C. Heald[9], and assigned by Gregory and others to the De Chelly sandstone. A detailed examination of this formation was made by the writer. It was found that the bottom member (No. 5 of Heald's Section) which immediately overlies Permian red shales and non-cross-bedded sand-

Fig. 8. Western edge of Defiance Uplift at Nazlini Canyon. Fossil footprint horizon in left center.

stones was similar in every essential detail to the lowermost member (No. 3 of the writer's section) of the De Chelly sandstone in Canyon de Chelly, and is probably to be correlated with that member. Likewise the 27 feet of chocolate-colored shaly sandstones immediately above (No. 4) seemed to correspond to the middle member (No. 2) of the section in Canyon de Chelly.

The third member of Heald's section, 77 feet thick, was found to be of extreme interest since many parts of it correspond very closely to Coconino sandstone that had already been traced eastward across the plateau nearly to this locality. These sandstones were found to be similar in uniformity and size of grain, in mineral content, in type of cement, and in the nature of cross-bedding. The sandstone of member 3 in Bonito Canyon differs from the Coconino sandstone to the west only in its position relative to the Shinarump conglomerate. In Bonito Canyon it is separated from the Shinarump

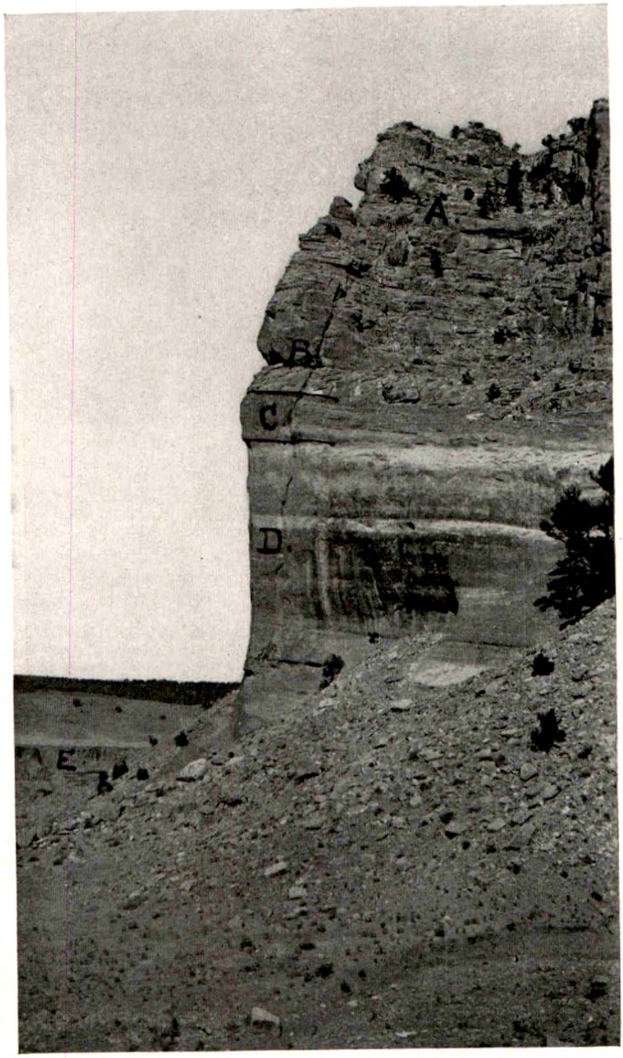

Fig. 9. Section in Bonito Canyon, Fort Defiance. A, Upper shales and fine sands; B, Sandstone of Coconino aspect; C, Non-cross-bedded, argillaceous sandstone; D, Sandstone of Lower DeChelly aspect; E, Underlying red beds.

by red beds which are largely horizontally-bedded (non-cross-bedded) and not greatly different from some of those found lower in the section. These red beds, however, may be explained as being a tongue of shaly sandstone extending into this area from the east or south, by a pre-Shinarump erosion of these red beds in the Kin-la-Chee locality, or by both.

SECTION OF DE CHELLY SANDSTONE AT WEST ENTRANCE OF BONITO CANYON, NEAR FORT DEFIANCE, MEASURED BY K. C. HEALD.

Comments by writer		Feet
	Shinarump conglomerate.	
	Unconformity.	
Mostly shaly sand not noted in other sections.	1. Sandstone, light red, fine-grained; clear-white and red rounded quartz grains; calcareous and ferritic cement; contains rare pebbles one sixty-fourth to one-sixteenth inch in diameter; massive, cross-bedded in places; weathers into rounded knobs; in two beds, 13 and 15 feet thick	28
	2. Sandstone, tan to brown, fine-grained; clear, well-rounded quartz; calcareous cement; many specks of limonite; even bedded to slightly cross-bedded; hard; forms nearly vertical cliff; in three beds, 7, 3, and 6 feet thick	16
Coconino aspect	3. Sandstone, chocolate-colored to gray-brown, fine to medium grained; clear, well-rounded quartz; massive; parts of the bed show no structure; other parts cross-bedded with curved laminae tangential to a horizontal surface; weathers in rounded bosses	77
Middle De Chelly aspect	4. Sandstone, chocolate-colored, shaly, largely concealed by talus	27
Lower De Chelly aspect	5. Sandstone, light red, fine grained; clear to red rounded quartz grains; bottom 5 feet thin bedded; in the center gray, cross-bedded, resistant sheet, 1½ feet thick; remainder massive, inconspicuously cross-bedded	115
Supai aspect	Moencopi shales	
		263

The relationship of the Coconino-like sandstone in Bonito Canyon to the cliff-forming upper member in Canyon de Chelly seems apparent when it is considered that here and also at Nazlini Canyon to the northwest, the De Chelly type of sandstone appears in many places to be mixed with the purer Coconino type. Certain parts of the upper walls of Canyon de Chelly suggest that a similar horizontal gradation may also be found there, although the Coconino element is obviously much less pronounced.

SANDSTONE AT NAZLINI CANYON.

The intermixture of Coconino and De Chelly sandstone types in the upper walls of Nazlini Canyon, which is ten miles south of Canyon de Chelly, has already been mentioned. Further evidence of the age of the sediments in this locality is found in the fact that numerous vertebrate footprints have been discovered within one hundred feet of the top of the formation. Most of the tracks were poorly preserved or were in slabs too large to be collected so no specific identifications were made. Their general nature, however, suggests a fauna similar to that represented at Kin-la-Chee, twenty miles to the south.

SUMMARY AND CONCLUSIONS.

The De Chelly sandstone of the Canyon de Chelly region is a well-defined formation composed principally of red cross-bedded sandstones which are different from the Coconino sandstone in type of cross-bedding, variety of grain size, mineral composition and kind of cement. The formation may be divided into three definite members which are usually easily recognizable by their manner of weathering, color and type of bedding.

Typical Coconino sandstone appears thirty miles south of Canyon de Chelly at Kin-la-Chee. There it occurs immediately beneath the Shinarump conglomerate and contains vertebrate footprints similar to those at Grand Canyon. To the north at Nazlini Canyon footprints are also found, not far below the Shinarump conglomerate, but the sandstone there shows a mixture of Coconino and DeChelly types. To the east the Coconino type appears in Bonito Canyon near Fort Defiance above the lower two members of the De Chelly sandstone and apparently mixing with or partly replacing the upper member. Above it are found red beds, mostly flat-lying, not seen in other sections.

It is believed that while the Coconino sands were being accumulated by winds from a source to the south[10], the upper part of the De Chelly sandstone was forming from sands of a different source, probably brought from the north as suggested by the remarkable uniformity of dip in the opposite direction. Sufficient detailed work on the De Chelly sandstone has not yet been done to explain the nature of its origin. It is worthy of note, however, that the cross-bedding in the lower member and in limited areas in the upper member is of the

type found in the Coconino, *i.e.*, curving laminae forming wedges which truncate one another, and this type probably is indicative of eolian deposition. On the other hand, the beds of the upper member were at least partially deposited by water as shown by the many intermediate non-cross-bedded layers of shaly sand.

WORK NEEDED.

At the conclusion of this brief field investigation it is felt that the relationship between the Coconino sandstone of the Grand Canyon region and the De Chelly sandstone of Canyon de Chelly has been definitely established. Furthermore, additional information concerning the De Chelly sandstone has been gathered, though by no means has enough yet been obtained to warrant anything more than a suggestion concerning the origin and history of this sandstone. It is recommended (1) that detailed studies of the sand grains and of the sedimentary structures, especially the types of cross-bedding, be made in Canyon de Chelly; and (2) that the nature and thickness of this formation in Monument Valley and its exact relationship to the Cedar Mesa sandstone in that area be determined.

1. Gregory, Herbert E., U. S. Geological Survey, Prof. Paper **93**, p. 31, 1917.
2. Darton, N. H., University of Arizona, Bull. **119**, p. 91, 1925.
3. Baker, A. A., and Reeside, John B., Jr., Amer. Assoc. of Petroleum Geologists Bull., Vol. **13**, No. 11, p. 1416, 1929.
4. Gregory, Herbert E., U. S. Geological Survey, Prof. Paper **93**, p. 27, 1917.
5. Hager, Dorsey, Mining and Oil Bull., Vol. **10**, pp. 167, 423, 1924.
6. Darton, N. H., University of Arizona, Bull. **119**, pp. 85, 91, 207, 1925.
7. Baker, A. A., and Reeside, John B., Jr., Amer. Assoc. of Petroleum Geologists Bull., Vol **13**, No. 11, p. 1426, 1929.
8. Gregory, H. E., U. S. Geological Survey, Prof. Paper **93**, p. 31, 1917.
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10. McKee, Edwin D., History and Origin of the Coconino Sandstone, Carnegie Institution of Washington Publ., No. **440**, 1933.

GRAND CANYON, ARIZONA.

SCIENTIFIC INTELLIGENCE.

GEOLOGY.

Survey of India. Geodetic Report, Vol. VIII, Oct. 1, 1931, to Sept. 30, 1932. R. H. THOMAS, Surveyor General. Pp. 118, with charts and plates. Dehra Dun, 1933 (5s. 3d.).—This volume opens with a brief statement of the important work done by Dr. J. de Graaf Hunter, a portrait forms the frontispiece. He was made director of the Geodetic Branch in 1928 and retired in November, 1932, because of the unavoidable retrenchment. The same cause has led to radical changes in the organization. Notwithstanding this, many valuable results are shown to have been obtained in connection with the observatories, also the tides, gravity, triangulation and levelling. A summary of these is given by Dr. de Graaf Hunter in the Introduction (pp. ix to xiv).

Attention must also be called to the chart XXI which gives an index of the Geodetic Surveys in India and neighboring countries; also to XXIII giving the results of these Surveys between India and Australia.

Publications of the United States Geological Survey; W. C. MENDENHALL, Director. Recent issues are noted in the following list.[1] (See earlier, vol. **25**, pp. 266, 267, and vol. **27**, pp. 71-73.)

TOPOGRAPHIC ATLAS.—Fifty-four sheets.

PROFESSIONAL PAPER.—No. 175. Title page, contents and index.

BULLETINS.—Alaska mineral resources, Nos. 844 C, D, 857 A, B (prices 5-15 cents).

Alaska Railroad Belt, Nos. 849 B, C, E, F, H, I (prices 15 to 35 cents).

Oregon, Eastern mining district, No. 846 A (25 cents); Takilma-Waldo district, No. 846 C (20 cents).

Also the following: 842. Metalliferous deposits of the greater Helena mining region, Montana; by J. T. PARDEE and F. C. SCHRADER. Pp. 318; 47 pls., 36 figs. (70 cents).

845. Guidebook of the Western United States, So. Pacific lines; by N. H. DARTON. Pp. 304; 49 pls., 29 route maps, 71 figs. ($1.00).

846 C. The Climax Molybdenum deposit, Colorado; by B. S. BUTLER, J. W. VANDERWILT, also C. W. HENDERSON. Pp. 195-237, pls. 23-38, figs. 27-31 (50 cents).

[1] These publications can be obtained as follows: 1. MAPS from the Director of the Survey, usual price of each sheet 10 cents, a discount of 40 per cent on orders of $5.00 or more. 2. REPORTS, at the prices given, from the Superintendent of Documents, Government Printing Office, Washington, D. C. *Remittance in each case by money order.*

858. Bibliography of No. America Geology, 1931, 1932; by J. W. NICKLES.

WATER SUPPLY PAPERS.—N. C. GROVER, Chief Engineer.—No. 639. Geology and ground-water resources of the Roswell Artesian Basin, New Mexico; by A. G. FIEDLER and S. SPENCER NYE with N. M. State Engineer. Pp. 372, 46 pls. (maps in pocket), 37 figs. (price $1.00).

656. Ground-water resources of western Tennessee; by F. G. WELLS and MARGARET D. FOSTER. Pp. vii, 319, 16 pls. (maps in pocket), 18 figs. (60 cents).

SURFACE WATER SUPPLY of the United States, 1932. Nos. 727, 729, 730, 731, 732, 733, 734, 735, 736, 739 (prices 10 to 20 cents).

CIRCULARS. No. 5. Geology of North and South McCallum Anticlines, Jackson Co., Colorado; by J. C. MILLER. No. 6. Mineral-water Supply of Mineral Wells Area, Texas; by SAMUEL F. TURNER.

Marine Mammals; by EARL L. PACKARD, REMINGTON KELLOGG, and ERNST HUBER. Carnegie Institution of Washington, Publication No. 447. Pp. 136, 8 pls., 41 text figures, 1934.—This consists of four papers. The first on "*A new Cetothere from the Miocene Astoria Formation of Newport, Oregon,*" by E. L. PACKARD and R. KELLOGG, contains the description of a cetothere, *Cophocetus oregonensis* (n. gen. and sp.), and discusses problems of correlation. The stratigraphic correlations combine the results of studies of invertebrates (especially Mollusca and foraminifera) and of vertebrates. Following, as it does, the recent work of H. G. Schenck (1928) and of T. J. Etherington (1931) on the Astoria, the present paper comes at an opportune time.

The second paper: *The Patagonian Fossil Whalebone Whale, Cetotherium moreni* (*Lydekker*), by R. KELLOGG, describes a new specimen of this form from the Lower Miocene of Patagonia and discusses the criteria for the diagnosis of the various types of cetotheres.

The third paper: *A new Cetothere from the Modelo Formation at Los Angeles, California*, also by R. KELLOGG, describes *Mixocetus elysius* (n. gen. et sp.) from the lower Upper Miocene. The age of the beds is based on foraminiferal evidence.

The fourth paper: *Anatomical Notes on Pinnipedia and Cetacea,* by the late ERNST HUBER, arranged by A. BRAZIER HOWELL, is a series of short chapters on the facial musculature of the Pinnipedia (Otariidae, Phocidae) and Cetacea (*Tursiops truncatus, Monodon monoceros*). The descriptions and excellent drawings show in a very clear manner the striking modifications that have taken place in these aquatic mammals. LESLIE E. WILSON.

The Deformation of the Earth's Crust: An Inductive Approach to the Problems of Diastrophism; by W. H. BUCHER. Pp. 531; 100 figs. Princeton, 1933 (Princeton University Press, $5.00).—This book marshals the great body of evidence on the deformation of the Earth's crust for the purpose of discovering the laws governing that deformation. Forty-six generalizations have been formulated as laws from the assembled evidence, and other generalizations, for which the evidence is deemed less secure, are presented as "opinions."

There are fifteen chapters dealing principally with the Earth's mobile belts and their behavior during orogenesis and epeirogenesis. Isostasy occupies one chapter, in which the highly probable conclusion is reached that isostasy does not cause diastrophism but merely modifies its effects. The world's literature has been carefully examined, and the resulting large number of citations makes the book a valuable reference work.

The author himself recognizes, as frankly stated in the preface, that most of the laws are of uncertain value and require further testing. Some of the laws were formulated earlier by other authorities, such as the laws taken over from Stille's "Grundfragen der vergleichende Tektonik," or from Washington (law 10: Washington's "law"); but most of them have been formulated by the author from an inductive examination of the world's literature. The induction of more than thirty generalizations that shall have the validity of laws is doubtless beyond the power of any single individual. The enormous amount of labor involved in inductively examining the evidence for only one generalization is well shown by Benson's memoir ("The tectonic conditions accompanying the intrusion of basic and ultrabasic igneous rocks": Nat Acad. Sci., Memoir, vol. 19, 90 pp., 1926), in which is tested the validity of Suess' generalization that "the green-rocks form sills in dislocated mountains, that sometimes follow the bedding planes and sometimes the planes of movement." This memoir, it would seem, might profitably be cited by the author. Furthermore, the ideas on the geology of the Alps held by certain Austrian geologists, notably Sander, Schmidt, Heritsch, and Ampferer, who have their feet more firmly planted on the ground than have the extreme nappists, should receive consideration.

The book brings together an immense number of contributions bearing on the problems of diastrophism, which have been critically examined and synthesized into organic unity. It thus constitutes a very notable achievement and should stimulate that discussion of the laws and opinions which is avowedly one of its main purposes.

ADOLPH KNOPF.

Preliminary Geologic Map of Maine; by ARTHUR KEITH. State of Maine Geol. Surv., 1933.—It is many years since a geological map of the state of Maine has been published, and now we have

a good but much-generalized one by Arthur Keith. The generalization of the map is due to the lack of fossils in the formations and to the little detailed geological work so far accomplished. The map has ten striking color patterns, 4 of igneous rocks, 5 of Paleozoic systems, and 1 of Pre-Cambrian. The prevalent trend of the formations is northeast. Most of southwestern Maine and much of the Atlantic border is of Pre-Cambrian gneisses and schists, cut by granites which are mainly of Carboniferous age, with Devonian and older times also represented. Two-thirds of the state has at the surface Silurian and Devonian marine formations cut by Devonian granites and rhyolites. Very little continental "Mississippian"is present, and at the southwest there is a considerable area of unfossiliferous strata which is correlated with the Pennsylvanian. This map should be a stimulus to the state of Maine to help development of geological knowledge, and especially to fix the age of the many granitic bodies—a very great desideratum in tectonics. C. S.

Revision of the Estonian Arthrodira. Part I. Family Homostiidae Jaekel; by ANATOL HEINTZ. Univ. Tartu, Geol. Inst., Pub. No. 38, 115 pp., 23 pls., 51 text figs., 1934.—In this excellent and detailed memoir Doctor Heintz restudies arthrodire material, numbering some 800 specimens, collected mainly by Professor Asmus between 1836 and 1856 in the middle Old Red Sandstone of Estonia, and used by him as the basis for his genera *Homostius* and *Heterostius*, two of "the most interesting representatives of the whole group." Heintz recognizes the family Homostiidae, with the genera *Angarichthys* and *Homostius*, and of the last-named genus he describes five species, one of which is new. This family is now known to occur in Estonia, Latvia, northwest Russia, Scotland, Spitzbergen, and Siberia. A complete skeletal restoration of *Homostius sulcatus* is given, showing it from the top and side. C. S.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Exploring the Upper Atmosphere; by DOROTHY FISK; with an introduction by H. L. BROSE. Pp. 166; 4 figs. and frontispiece. New York, 1934. (Oxford University Press, $1.75).—The stratosphere or upper atmosphere has loomed into sudden importance in recent years and is now being explored in several novel ways. Popular attention was sharply focussed upon this region by Picard's invention in 1931 of a balloon capable of taking observers to vast heights while permitting them to breathe air of sea-level density. But for a number of years before this striking event, less spectacular research had been going on by meteor-

ologists, spectroscopists, theoretical physicists, radiologists and astronomers. In fact, as Miss Fisk points out, a hint of peculiar qualities in the upper atmosphere was thrown out nearly three centuries ago by Samuel Pepys, of Diary fame.

Books that succeed in being both popular and authoritative are rare. The attempt to accomplish this double feat is particularly difficult in this case, since, as we have indicated, it is necessary to call upon so many departments of knowledge to make the account complete. All in all, Miss Fisk has succeeded well. The portions that deal with astronomy are, however, below the general standard of the book, and for a second edition the author will doubtless call upon the good offices of a colleague acquainted with that science. Even here there is no really serious misstatement except that the planet Eros "vanished one fine January morning in the year 1932 and was no more." How interesting an event this would be, and what a pity that nothing of the kind happened. The book is written in a delightfully informal and occasionally humorous style. The general reader will enjoy and profit by its perusal. Very few men of science will fail to be surprised to learn that so many sciences in addition to their own have been exploring this comparatively new region. The introduction by Professor Brose of Nottingham is an excellent historical account of atomic theory; it forms an appropriate introduction to the subject proper.

FRANK SCHLESINGER.

Easily Interpolated Trigonometric Tables with Non-Interpolating Logs, Cologs, and Antilogs (No. 7 of the Simplified Series); by FREDERICK W. JOHNSON, 50 pages of introduction, 190 pages of tables. San Francisco, 1933 (The Simplified Series Publishing Co., semi-loose-leaf without cover, $1.70; with paper cover, $1.85, three-ring leather-like cover, $2.45; flexible fabrikoid binder, $3.50).—By the novel arrangement used in this book, four-and five-place logarithms and antilogarithms and four-place cologarithms may be obtained by mere inspection without any calculation whatever. Another table gives five-place cologarithms of all three-place numbers. The five-place tables of natural and logarithmic values of trigonometric functions are presented in the usual arrangement and are supplied with tables of proportional parts which enable one to interpolate to seconds in one single step. These values are given for each minute of each angle and, in addition, the logarithmic functions for 0° to 3° and for 87° to 90° are given at intervals of one second. Another feature of this book is a table of constants with their logarithms and cologarithms which are of especial value in solving scientific problems. This table includes atomic weights, metric conversion factors, chemical, physical, and mathematical constants, and all common fractions of two digits.

A. W. HAWLEY.

THOMAS YOUNG, F. R. S., *Philosopher and Physician*; by FRANK OLDHAM. Pp. 159; 1 plate and frontispiece, 14 figs. London, 1933 (Edward Arnold and Co.; Longmans, Green & Co., New York, $2.40).—This brief biography makes delightful reading for anyone who is interested in the personality and the career of a versatile scholar of outstanding ability, whose work includes contributions especially to medicine, natural science and Egyptology.

A. T. W.

An Introduction to the Teaching of Science; by ELLIOT ROWLAND DOWNING. Pp. vii, 257, 30 tables. Chicago, 1934 (University of Chicago Press, $2.00).—This book is used as a text by the author for a course of the same name in the Department of Education of the University of Chicago. After making a distinction between "producer" science or science for scientists, and "consumer" science or science for the average individual, the author deals chiefly with the teaching of science to the latter class. Both the objects to be attained and the means to that end are skillfully discussed, and evidence is given where available of the results of research on this question. A. T. W.

Report of the Secretary of the Smithsonian Institution, CHARLES G. ABBOT; also of the Board of Regents, ending June 30, 1933. Pp. 193. Of the outstanding events of the year, Dr. Abbot mentions the first of a series of cruises in the interest of oceanography, sponsored by Mr. Eldridge K. Johnson. This cruise, which embraced the Porto Rican depth, has given important results. Another matter of interest is the addition of art subjects, valued at $4,000,000, to the National Gallery; these bear the name of the donor, Mr. John Gellathy. It is further notable that a new Astrophysical Observatory is being established on Mt. St. Katherine, near Mount Sinai in Egypt. This, the gift of Mr. John A. Roebling, will take the place of the not entirely satisfactory station on Mt. Brukkaros. Important accessions have also been made to the National Zoological Park. All of these subjects, with others, are discussed in detail by the respective directors in charge of the individual departments.

The Institution has also published the usual volume containing a preliminary account of the explorations and field work in 1933. This, with the many illustrations, is of decided interest, although the necessity of severe economy has made necessary the restriction of the whole to a pamphlet of 59 pages.

OBITUARIES.

DR. GOODWIN DELOSS SWEZEY, professor emeritus of astronomy at the University of Nebraska, died on July 10 at the age of eighty-three.

Dr. Henry Arnstein, chemist and engineer of Philadelphia, died on July 24 at the age of forty-eight.

Dr. Stephan Richarz, professor of geology at the Fu-Jen University, Peiping, China, died on July 14 at the age of sixty.

Dr. Benjamin W. Hunt, past-president of the Georgia State Horticultural Society, and member of the Board of Trustees of the Georgia Experiment Station, died on June 26 at the age of eighty-seven.

Dr. Mary Violette Dover, associate professor of chemistry at the university of Missouri, known for her work on petroleum, died on August 8.

Dr. Marion Newbigin, editor of the Scottish Geographical Magazine, died on July 20.

Dr. M. Benjamin Baillaud, honorary director of the Paris Observatory, died on July 8, aged sixty-eight.

Dr. Leonard Cockayne, the noted ecological botanist, died early in July at the age of seventy-nine.

Dr. Bertram Dillon Steele, emeritus professor of Chemistry in the University of Queensland, died on April 12 at the early age of sixty-three.

PUBLICATIONS RECENTLY RECEIVED.

Researches on Fungi, Volume V; by A. H. Reginald Buller. London, 1933 (Longman's, Green and Co., Ltd., 25/ net.)

Geologic History at a Glance; compiled by L. W. Richards and G. L. Richards, Jr. Stanford, Calif., 1934. (Stanford University Press, $.80, $1.25).

The Naturalist on the Prowl; by Frances Pitt. New York, 1934 (The Macmillan Co., $2.00).

The Practice of Absorption Spectrophotometry; by F. Twyman and C. B. Allsopp, 2d Edition. London, 1934 (Adam Hilger, Ltd., 12s. 6d.).

Moral, Wille und Weltgestaltung Grundlegung zur Logik der Sitten von Karl Menger. Vienna, 1934 (Julius Springer, RM. 6.80).

Grundzüge der Geologie und Lagerstättenkunde Chiles; von J. Brüggen. Leipzig, 1934 (Max Weg; broschiert MK. 30, gebunden MK. 33).

Papers from the Geological Department, Glasgow University; Volume XV (Octavo Papers of 1931-1934), Volume XVI (Quarto Papers of 1931-1934). Glasgow, 1934 (Jackson, Wylie & Co.).

Carnegie Institution of Washington. Publication No. 423. The Building of the Roman Aqueducts; by Esther Boise Van Deman. Publication No. 450. Diametral Changes in Tree Trunks; by Ferdinand W. Hoasis. News Service Bulletin, Vol. III, No. 17. Renewing the Days of Forty-nine; by Ralph W. Chaney.

Smithsonian Miscellaneous Collections, Vol. 92. No. 1. The Hypotrochanteric Fossa of the Femur; by Ales Hrdlicka. No. 2. New Fresh-Water Mollusks from Northern Asia; by Alan Mozley. No. 3. Lethal Response of the Alga Chlorella Vulgaris to Ultraviolet Rays; by Florence E. Meier. No. 4. A New Original Version of Boscana's Historical Account of the San Juan Capistrano Indians of Southern California; by John P. Harrington.

AMERICAN JOURNAL OF SCIENCE

OCTOBER 1934

A SUGGESTED FORM OF CRYSTALLOGRAPHIC PRESENTATION.

M. A. PEACOCK.

Since the appearance of the sixth edition of Dana's *System of Mineralogy* (1892) many crystallographers have come to appreciate the convenience and accuracy of Victor Goldschmidt's two-circle goniometer and have adopted this instrument in their determinative and research work. In the projected new edition of the *System* it seems proper to recognize this extensive and fruitful use of the two-circle goniometer, and to express the crystallographic data so as to serve the two-circle worker as well as the user of instruments measuring the interfacial angles. This paper explains the form of crystallographic presentation which the author and his senior associates, Professor Charles Palache and Dr. Laurence LaForge, have developed in the course of their work of revising the crystallography of the *System*; its object is to place this form before crystallographers for comment.

THE TWO-CIRCLE METHOD.

For the proper understanding of what follows a brief statement of the essentials of Goldschmidt's two-circle method of crystal measurement and discussion is required.[1]

The two-circle goniometer measures the azimuth (ϕ) and polar distance (ρ) of any face (hkl) on a crystal with respect to the axis of the principal zone as pole and the meridian through a chosen face in the principal zone as zero meridian (figure 1).[2] From the co-ordinate angles (ϕ, ρ) of a sufficient

[1] For an exhaustive treatment consult V. Goldschmidt's *Index der Krystallformen*, I, pp. 1-156, Berlin, 1886.

[2] Two-circle measurement by zone adjustment is the normal procedure and the one that is implied throughout this paper. The alternative two-circle procedure, namely, measurement from a prominent face as pole (see T. V. Barker, *Graphical and Tabular Methods in Crystallography*, London, 1922, p. 13; M. H. Hey, *Min. Mag.*, 23, p. 560, 1934) is equivalent to measurement from a zone axis as pole when the chosen face is normal to a zone axis. In general, however (triclinic system), two-circle measurement by face adjustment gives angles that are not directly comparable to those obtained by zone adjustment.

number of faces the geometrical crystallography of the crystal can be expressed in any desired form, most directly in terms of Goldschmidt's polar elements and symbols.

The polar elements of Goldschmidt are, in the general case, five independent quantities, p_0, q_0, $r_0=1$; λ, μ, ν (figure 2)

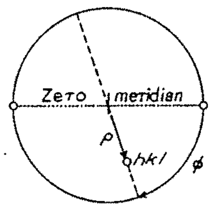

Fig. 1. Two-circle co-ordinate angles (ϕ, ρ).

defining the geometrical form of a parallelopiped (polar form) which is reciprocal to the conventional parallelopiped (primitive form) defined by the linear elements, a, $b=1$, c; α, β, γ (figure 3). The edges of the polar form (the polar axes) are normals to the faces of the primitive form (the

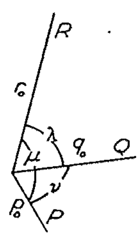

Fig. 2.

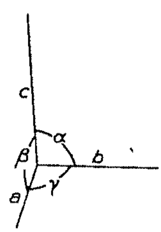

Fig. 3.

Fig. 2. Polar axial lengths (p_0, q_0, r_0) and axial angles (λ, μ, ν).
Fig. 3. Linear axes (a, b, c) and axial angles (α, β, γ).

axial planes); and conversely, the edges of the primitive form (the linear axes) are normals to the faces of the polar form. The following fundamental relation connects the polar and linear elements:

$$a:b:c=\sin\alpha/p_0:\sin\beta/q_0:\sin\gamma/r_0=\sin\lambda/p_0:\sin\mu/q_0:\sin\nu/r_0 \quad (1)$$

The polar symbol for the general form, pq ($r=1$), is directly comparable to the Miller symbol, ***hkl***, which is itself a reciprocal symbol.

$$p = h/l;\ q = k/l \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Two-circle measurements are conveniently plotted on the gnomonic projection which gives an immediate solution of the polar elements and polar (or Miller) symbols. In the rectangular systems the gnomonic projection gives the polar

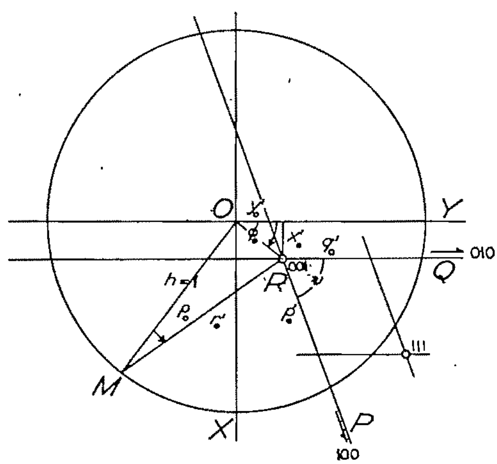

Fig. 4. Gnomonic projection of the triclinic faces (100), (010), (001), (111), on the plane normal to the axis of the prism zone, at unit distance from the crystal centre, showing the five independent projection elements, x_0', y_0', p_0', q_0', ν.

elements directly; in the inclined systems the projection gives projection elements, distinguished by the affix ($'$), which are simply related to the polar elements.

Figure 4 shows these relations in the general case. The poles of the four faces of a triclinic crystal, 100, 010, 001, 111, fix the polar axes, $P\ Q\ R$, and define the five projection elements on the plane of the gnomonic projection:

p_0', q_0' unit lengths on the projected polar axes, P, Q;
x_0', y_0' rectangular linear co-ordinates of the pole 001;
ν the angle between the axes, P, Q.

Join OR. Swing the crystal centre M about OR into the plane of the projection. Let ϕ_0, ρ_0 be the co-ordinate angles of the pole 001.

Then

$$\tan \phi_0 = x_0'/y_0' \quad (3)$$
$$\tan \rho_0 = x_0'/\sin \phi_0 = y_0'/\cos \phi_0 \quad (4)$$

and

$$p_0 = p_0' \cos \rho_0 \quad (5)$$
$$q_0 = q_0' \cos \rho_0 \quad (6)$$
$$r_0 = r_0' \cos \rho_0 = 1 \quad (7)$$
$$\cos \lambda = y_0' \cos \rho_0 \quad (8)$$
$$\cos \mu = (x_0' \sin \nu + y_0' \cos \nu) \cos \rho_0 \quad (9)$$

CRYSTALLOGRAPHIC INVERSION.

The principal zone of a crystal is usually an axial zone. Commonly the c-axis is the axis of the principal zone; occasionally it is the a-axis or the b-axis. The normal procedure of two-circle measurement thus leads almost without exception to a projection and elements that refer to a crystallographic axis as pole, usually the c-axis, sometimes the a-axis or the b-axis. These three positions will be denoted as normal position, first inversion and second inversion respectively.[8] They are obtained by rotation of the axes according to the following scheme (figures 5-7), in which P, Q, R represent the positive polar axes. Poles in the first (front right) octant in normal position thus remain in the first octant in the inverted positions.

Normal position. c-axis vertical; P-, Q-axes horizontal; Q-axis to the right.

Projection elements: x_0', y_0', p_0', q_0', ν; co-ordinate angles: ϕ, ρ.

First inversion. a-axis vertical; Q-, R-axes horizontal; R-axis to the right.

Projection elements: x_1', y_1', q_1', r_1', λ; co-ordinate angles: ϕ_1, ρ_1.

Second inversion. b-axis vertical; R-, P-axes horizontal; P-axis to the right.

Projection elements: x_2', y_2', r_2', p_2', μ; co-ordinate angles: ϕ_2, ρ_2.

In the general (triclinic) case inversion of the axes involves non-rectangular rotations. Goldschmidt's three positions

[8] The term "inversion," which is not preoccupied in crystallography, is suggested by an analogy in musical harmony. The position of a common chord (triad) is changed from root position to first inversion and second inversion by cyclic transposition of its three notes by which each in turn is made the bass note of the chord.

(*Winkeltabellen*, 1897, p. 6), obtained solely by rectangular rotations, are thus the same as ours only in the rectangular systems and in the second inversion of the monoclinic system.

The affixes here used to distinguish elements and angles in inverted positions are self-explanatory and they overcome an inconsistency in Goldschmidt's usage. Goldschmidt used the affixes (′) and (″) to distinguish elements and angles in his first and second inversions respectively and also the affix (′) to denote projection elements in any position as distinct from polar elements. Our proposal to confine the use of the affix

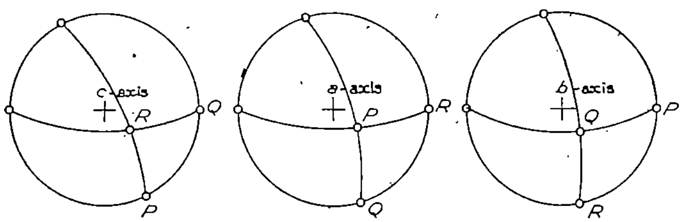

Fig. 5. Fig. 6. Fig. 7.

Fig. 5. Normal crystallographic position (c-axis vertical).
Fig. 6. First inversion (a-axis vertical).
Fig. 7. Second inversion (b-axis vertical).

(′) for projection elements and use the subscript numerals, $_0$, $_1$, $_2$, to denote normal position, first inversion and second inversion respectively avoids this ambiguity.

Rotation of the crystallographic axes does not affect the relative lengths of the axes, the axial angles, any angles between faces, or the symbols of the faces. The polar axial ratio is reduced to the form in which the polar axis normal to the pinacoid in basal position is unity. In the projection elements the projected lengths of the polar axes are reduced so that the projected polar axis normal to the pinacoid in basal position equals secant ρ_0, where ρ_0 is the polar distance of that pinacoid. In the rectangular systems and in the monoclinic system in second inversion $\rho_0 = 0^\circ$ and, therefore, the projected elements are equal to the corresponding polar elements; in these cases the affix (′) is omitted from the projection elements.

For the sake of consistency the polar axes, like the linear axes, will be written as a ratio: $p_0 : q_0 : 1$; $q_1 : r_1 : 1$; $r_2 : p_2 : 1$. Projection elements that differ from the corresponding polar elements, as they do in all positions in the triclinic system and

in the normal position and the first inversion in the monoclinic system, will be written as absolute quantities. In each case the relative length of the projected third polar axis (r_0', p_1', q_2') will be omitted, as it does not equal unity, is not an independent quantity, and is of no practical value.

This condensed statement of the two-circle method with certain modifications applies to the general case of the triclinic system. The notable simplifications of all the relations in the systems of higher symmetry are evident on inspection of the figures and formulas given.

ELEMENTS.

The conventional linear elements in normal position are fundamental and universally used. In the proposed form of crystallographic presentation they are retained and placed immediately after the crystal system of the species, followed by the polar elements in normal position. These two sets of elements define the primitive form and the corresponding reciprocal polar form. In the inclined systems the projection elements will also be given in suitable position, and to these will be added in certain cases, as explained later, polar elements in one or both of the inverted positions.

SYMBOLS.

The universally used Miller symbol, *hkl*, will be retained. The Goldschmidt symbol, *pq*, which is given directly by the gnomonic projection, can be transformed into the Miller symbol on inspection (equation 2), and hence to economize space it will be omitted.

ANGLES.

Following the linear axes Dana gives certain fundamental angles and a list of calculated interfacial angles designed to assist the determinative worker using a single-circle or contact goniometer. This list of angles is an arbitrary selection, the choice and arrangement of which are determined by the complexity of the form list and the habit of the mineral. In general, the interfacial angles do not include the co-ordinate angles of the two-circle goniometer.

To connect this system of co-ordinate angles with the current system of interfacial angles, Goldschmidt devised a system of auxiliary angles on rectangular axes, which he used

consistently, regardless of crystal system, in his *Krystallographische Winkeltabellen* (1896). Goldschmidt's complete system of angles, comprising the two co-ordinate angles, ϕ, ρ, and four auxiliary angles, ξ_0, η_0, ξ, η (figure 8), is admirably adapted to the rectangular systems. Each of the Goldschmidt angles is a possible interfacial angle, and the full table contains all the angles that the single-circle worker might expect to find in a table of interfacial angles. In the inclined systems, how-

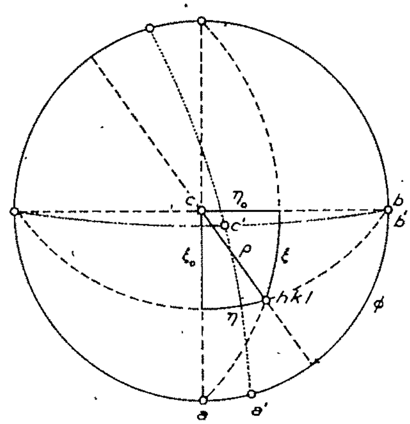

Fig. 8. Victor Goldschmidt's co-ordinate angles (ϕ, ρ) and auxiliary angles (ξ_0, η_0, ξ, η), showing their practical character in the orthorhombic system (pinacoids, *a*, *b*, *c*) and their largely unserviceable nature in the triclinic system (pinacoids, *a'*, *b'*, *c'*).

ever, notably in the triclinic, Goldschmidt's complete system of angles becomes artificial and unpractical; few of the angles (in general three in the monoclinic system and only one in the triclinic) are possible interfacial angles. This is probably the principal reason why only a few two-circle workers have used the form of the full Goldschmidt table in their publications.

Co-ordinate angles are necessary for the two-circle worker; it remains to decide on a system of interfacial angles that will meet the needs of the observer using any other type of instrument.

Of several schemes considered, a form used by N. v. Kokscharow[4] appears to offer the best solution. In his angle-

[4] *Mat. Min. Russl.*, IV, St. Petersburg, 1862, p. 356. The same form was used by L. J. Spencer, *Min. Mag.*, XXI, p. 153, 1926.

table for pyroxene Kokscharow gave three angles for each form, namely, $(hkl):(100)$, $(hkl):(010)$, $(hkl):(001)$. We have adopted this scheme of interfacial angles in our preliminary work, using the letters A, B, C for the three angles respectively.

$$A = (hkl):(100)$$
$$B = (hkl):(010)$$
$$C = (hkl):(001)$$

A table with these three angles for each form gives all Dana's fundamental angles, all the classification angles of Barker[5] (if the elements were chosen by Barker's rules), all the polar distances that would be obtained from two-circle measurement with any pinacoid as pole, and, on inspection, the angle between any two faces in a zone with a pinacoid. Such a table includes the great majority of angles that might be measured with a contact or single-circle goniometer. With some modification in the hexagonal system, the system of angles to the pinacoids can be applied consistently in all the crystal systems, and thus the user will know exactly which angles he will find and where he will find them. A table combining co-ordinate angles and the angles to the pinacoids seems to provide the data needed by the observer using any type of goniometer.

TRICLINIC SYSTEM.

In the triclinic system permutation of the axes involves non-rectangular rotations. The relations of the projection elements and co-ordinate angles in the three positions are not simple. A full two-circle statement in each of the three positions would be very elaborate and it is doubtful if the value of the data in the two abnormal positions would repay the labor of preparing the extra material and justify the space it would occupy. It therefore seems best to confine the two-circle statement to one position, namely, that determined by the axial zone which is habitually developed prismatically. Ordinarily this position is the normal position, since the principal zone is conventionally chosen as the prism zone. The proposed form of angle-table for a normal triclinic mineral then takes the form given in the following table.

[5] *Systematic crystallography* (1930).

MEYERHOFFERITE.

Triclinic. $a:b:c = 0.7904:1:0.7763$; $\alpha = 90°41'$, $\beta = 101°51'$, $\gamma = 86°44'$.[6]
$p_0:q_0:r_0 = 0.9837:0.7610:1$; $\lambda = 89°59'$, $\mu = 78°10\frac{1}{2}'$ $\nu = 93°11\frac{1}{2}'$.
$p_0' = 1.0051$, $q_0' = 0.7775$; $x_0' = 0.2098$, $y_0' = 0.0003$.

Form	ϕ	ρ	A	B	C
E 212	74°39′	51°31½′	42°05′	78°02½′	49°49′
u $\bar{1}11$	—43 35½	49 01½	123 23	56 51	57 39
p $\bar{1}\bar{1}1$	—132 15½	47 00½	120 52	119 28	56 12½

etc.

The significance of the elements and angles in this table is evident from figure 4, which shows the projection elements on the gnomanic projection, and figure 9, which gives the co-

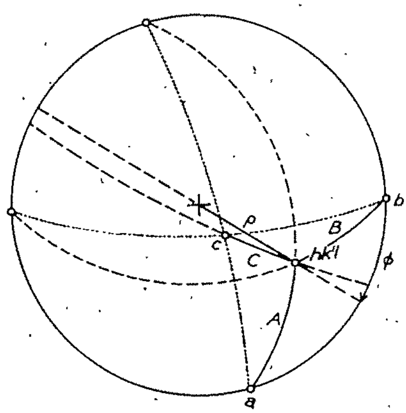

Fig. 9. Co-ordinate angles (ϕ, ρ) and angles to the pinacoids (A, B, C) in the triclinic system in normal position.

ordinate angles and the angles to the pinacoids for a pyramid face of a triclinic crystal in normal position.

There are, apparently, no triclinic minerals with the *a*-axis habitually in the axis of the principal zone, and consequently the first inversion appears to have no practical application in the triclinic system. There are, however, several triclinic minerals[7] habitually elongated with the *b*-axis. For such

[6] Elements in new position by C. Palache, based on measurements by W. T. Schaller (U. S. Geol. Sur. Bull. 610, p. 35, 1916) and new observations (unpublished).

[7] The wollastonite group, which comprises wollastonite, voglite, pectolite, schizolite and possibly rosenbuschite. The orientation of this isomorphous triclinic group is prescribed by the homeomorphism of wollastonite with the monoclinic form of wollastonite (parawollastonite). See forthcoming studies by the writer.

minerals the angle-table gives projection elements and co-ordinate angles (figure 10) in second inversion.

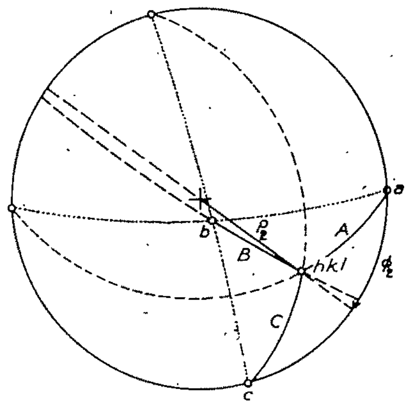

Fig. 10. Co-ordinate angles (ϕ_2, ρ_2) in second inversion and angles to the pinacoids (A, B, C) in the triclinic system.

PECTOLITE.

Triclinic. $a : b : c = 1.1369 : 1 : 0.9993$; $\alpha = 90°23\frac{1}{2}'$, $\beta = 95°14'$, $\gamma = 102°42\frac{1}{2}'$.[*]
$p_0 : q_0 : 1 = 0.9010 : 1.0201 : 1$; $\lambda = 88°25'$, $\mu = 84°33'$, $\nu = 77°12\frac{1}{2}'$.
$r_2' = 1.0053$, $p_2' = 0.9058$ $x_2' = 0.0068$, $y_2' = 0.2271$.

Form	ϕ_2	ρ_2	A	B	C
I $\bar{1}11$	120°03½′	49°20½′	112°20′	46°15′	51°52′
A $\bar{1}21$	109 20½	28 15½	99 01½	34 11½	64 32½
X $\bar{1}\bar{1}1$	—43 46½	55 09½	126 21	133 12	55 18½

etc.

MONOCLINIC SYSTEM.

In the monoclinic system the vertical zone is commonly prismatically developed, in which case two-circle measurement leads to a projection in normal position. Prismatic development with the a-axis is rare but prismatic development with the b-axis is common and consequently the second inversion is important. Even in cases of normal development it is often convenient to measure and discuss a monoclinic crystal with the symmetry axis as the pole. It seems desirable, therefore, to give elements and angles both in normal position and in second inversion for monoclinic crystals. Since the rotations

[*] Elements by M. A. Peacock (unpublished study), based on measurements of new material that proved the triclinic symmetry of the mineral.

involved in changing from one position to the other are rectangular the relations between the elements and angles in the two positions are simple and a table combining the required angles with the angles to the pinacoids is not elaborate. Figure 11 shows the angles for a pyramid face of a monoclinic

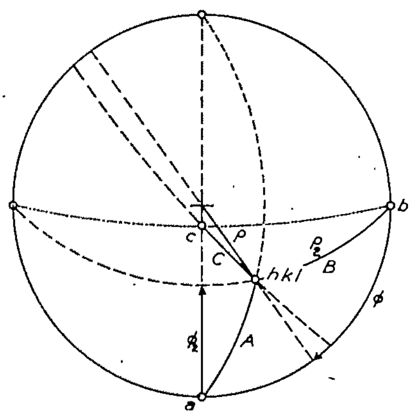

Fig. 11. Co-ordinate angles (ϕ, ρ) in normal position and (ϕ_2, ρ_2) in second inversion and angles to the pinacoids (A, B, C) in the monoclinic system.

crystal in normal position and second inversion. Through the equality of ρ_2 and B, co-ordinate angles in normal position and second inversion and the angles to the pinacoids can be given in a table with six columns of angles.

LANSFORDITE.

Monoclinic. $a : b : c = 1.6449 : 1 : 0.9567$; $\beta = 101°46'$.[a]
$p_0 : q_0 : 1 = 0.5818 : 0.9367 : 1$; $\mu = 78°14'$.
$r_2 : p_2 : 1 = 1.0676 : 0.6211 : 1$.
$p_0' = 0.5942$, $q_0' = 0.9567$; $x_0' = 0.2083$.

Form	ϕ	ρ	ϕ_2	$\rho_2 = B$	C	A
o 211	55°35½′	59°26′	35°36′	60°53′	50°00½′	44°14′
v 321	46 08	70 05½	26 40	49 20½	61 52	47 19
r $\bar{1}$11	—21 58½	45 53½	111 06½	48 15	51 12	105 35

etc.

[a] Elements by L. LaForge, recalculated from measurements by S. L. Penfield (this Journal, 39, p. 121, 1890), G. Cesàro (Acad. Roy. Belge, Classe des Sci., Bull. 1910, 4, p. 234), H. Leitmeyer (Z. Kryst., 47, p. 104, 1910) and M. Fenoglio (Per. di Min. 4, p. 443, 1933).

ORTHORHOMBIC SYSTEM.

In this system each of the three rectangular axes is equally valid as the vertical axis and consequently there is much variety in the adopted orientations. Also different crystals of a single species may be developed prismatically in the direction

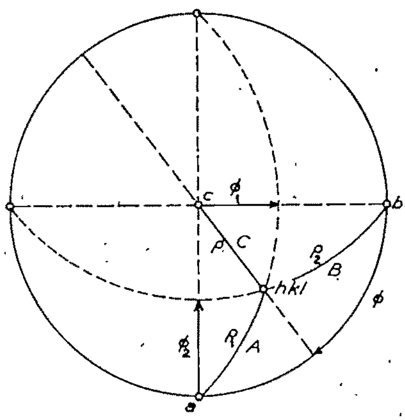

Fig. 12. Co-ordinate angles (ϕ, ρ) in normal position, (ϕ_1, ρ_1) in first inversion and (ϕ_2, ρ_2) in second inversion and angles to the pinacoids (A, B, C) in the orthorhombic system.

of different axes or tabular to different pinacoids. The normal position and the two inverted positions thus acquire equal systematic and practical importance. The following table gives elements and co-ordinate angles for an orthorhombic mineral in all three positions. The table also contains the three angles to the pinacoids since these angles are the three polar distances (figure 12).

LORENZENITE.

Orthorhombic. $a : b : c = 0.6103 : 1 : 0.3636.$[19] $p_0 : q_0 : 1 = 0.5957 : 0.3636 : 1.$
$q_1 : r_1 : 1 = 0.6104 : 1.6787 : 1.$ $r_2 : p_2 : 1 = 2.7503 : 1.6384 : 1.$

Form	ϕ	$\rho = C$	ϕ_1	$\rho_1 = A$	ϕ_2	$\rho_2 = B$
m 110	58°36½′	90°00′	90°00′	31°23½′	0°00′	58°36½′
p 111	58 36½	34 54½	19 58½	60 45½	59 13	72 39½
o 231	47 32	58 14½	47 29	51 09½	40 00½	54 58

etc.

[19] Elements by L. LaForge, recalculated from measurements by G. Flink (Medd. om Grönland, 14, p. 250, 1898; 24, p. 130, 1901).

HEXAGONAL, TETRAGONAL AND CUBIC SYSTEMS.

In the dimetric systems the crystallographic presentation reduces to one linear element $(a:c)$, one polar element $(p_0:r_0)$, co-ordinate angles in normal position and angles to the axial planes. Inversions are of no practical importance since it is usually easy to distinguish the unique vertical axis. In the isometric system the three axes are equivalent and a single table with one pair of co-ordinate angles and the angles to the faces of the cube for all known forms of the system suffices for all species.

RELATION OF THE NEW ANGLES TO GOLDSCHMIDT'S STANDARD ANGLES.

Many of the angles required for the form of angle-table proposed are the same as Goldschmidt's angles or complementary to them and consequently they are readily calculated by the usual formulas or extracted from a standard Goldschmidt table.

Orthorhombic System		Monoclinic System		Triclinic System	
New form	Gdt.	New form	Gdt.	New form	Gdt.
ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
$\rho = C$	ρ	ρ	ρ	ρ	ρ
ϕ_1	η_0	ϕ_2	$90^\circ - \xi_0$	ϕ_3	...
$\rho_1 = A$	$90^\circ - \xi$	$\rho_2 = B$	$90^\circ - \eta$	ρ_3	...
ϕ_2	$90^\circ - \xi_0$	C	...	A	....
$\rho_2 = B$	$90^\circ - \eta$	A	$90^\circ - \xi$	B	$90^\circ - \eta$ (Gr)
				C	......

In the rare case of second inversion in the triclinic system the co-ordinate angles (ϕ_2, ρ_2) must be calculated from the second inversion elements. The angle C in the monoclinic system and the angles A and C in the triclinic can be calculated from the expression giving the angle Δ between any two poles whose co-ordinate angles $(\phi_I, \rho_I; \phi_{II}, \rho_{II})$ are known:

$$\text{Cos}\,\Delta = \cos\rho_I \cos\rho_{II} + \sin\rho_I \sin\rho_{II} \cos(\phi_{II} - \phi_I) \quad \ldots \quad (10)$$

The proposed form of crystallographic presentation appears to combine the full requirements of workers using any type of goniometer. The few innovations, A, B, C, to denote angles to the axial planes, a general scheme of crystallographic inversions, and a slight modification of Goldschmidt's symbols for elements and angles in the inverted positions, should be immediately understood and easily remembered. In saving the space used by Dana's obsolete symbols for crystal forms

and that occupied by the repetition of form letters in tables of interfacial angles, the new form of table occupies but little more space than the older and, for present purposes, less useful style of presentation. By removing a number of unserviceable quantities and columns from the heading and body of Goldschmidt's type of angle-table and adding others that are useful, the proposed form of table requires little more than one-half the space that Goldschmidt's form demands.

Now that the relations of crystal structure and crystal morphology are being studied and clarified, and certain X-ray measurements are within the field of determinative technique, it seems that a handbook of mineralogy should include the more important röntgenographic constants in the crystallographic presentation. This matter has only recently come under consideration and here also suggestions will be appreciated. At the moment the following data appear to be those that might be profitably included:

1. The space group, if known.
2. The constants defining the unit cell.
3. A note indicating the relations of the structure cell to the crystallographic primitive form.
4. A note on the structure type.
5. The chemical formula of the unit cell. This would find place in the presentation of the chemistry of the species.

Further structural details seem to be outside the scope of a mineralogical manual.

SUMMARY.

It is believed that the projected new edition of Dana's *System of Mineralogy* should meet the requirements of crystallographers using the Goldschmidt two-circle goniometer. For this purpose a form of crystallographic presentation is developed and submitted for comment. The proposed statement combines what is essential in two-circle presentation (polar elements and co-ordinate angles) with an improved conventional presentation (linear elements, Miller symbols and angles to the pinacoids) which, it is believed, will serve the single-circle worker better than the current arbitrary lists of interfacial angles. The inclusion of selected X-ray data is considered desirable.

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AUTO RADIO—AN AID IN GEOLOGIC MAPPING.

ERNST CLOOS.

Abstract.

Recent experiments have proved that the quality of wireless reception from certain stations is influenced by geologic conditions of the underground. Structural disturbances such as faults or steeply dipping rock contacts cause "dead spots." A radio survey of such localities gives valuable indications for determining geologic structure on the one hand and for guiding the installation of radio sets and transmitting stations on the other. A small alteration in an ordinary automobile radio set is sufficient for determining such disturbances quantitatively and qualitatively.

Contents:

- Introduction
- Equipment
- Method
- The phenomena
- Interpretation of phenomena
  - Interferences
    - By man-made equipments
    - By cosmic influences
  - The geologic component
  - Response to different stations
- Results
  - The fault at Riderwood
  - Rock boundaries
  - The dip angle
  - Observations in Wyoming
  - Failures
- Literature

Introduction.

Accidental recognition of disturbances in the reception with an automobile radio set have led the writer to a series of experiments and observations that promise to be of value to geologists and geophysicists. The experiments were extremely simple and were carried out in regions in which the geologic structures were known. Observations in Wyoming have confirmed the observations and assumptions derived from local disturbances north of the city of Baltimore. Physical and technical considerations are not given in this paper intentionally. I wish to present the observed facts for criticism and use by specialists. A series of physical experiments are in progress. A more detailed and thorough discussion of the physical side of the phenomena will follow in a second paper.

I wish to express my sincere thanks to Dr. Robert Balk, who furnished the equipment with which the experiments were carried out.

Equipment.

The equipment used during the experiments consists of an automobile radio set, Majestic, model 1933, with local and long-distance switch. The latter is very valuable in checking the station used in doubtful regions as well as in detecting the intensity of the disturbance.

The car used was a Nash coupé, 1932, model 960. The aerial was attached to the roof of the car. The battery was the ordinary car battery. All wires and contacts were shielded against motor and other interferences from mechanical parts of the car. None of these arrangements were changed during the observations, in order to exclude any change in constants. Under normal conditions, with or without running motor, the set picked up any station within reach without noises or disturbances. The constant supervision of all mechanical parts is of extreme importance for eliminating uncertain factors that might influence the measurements.

Only the following Baltimore stations were used:

WCAO	600 K—	250 W
WBAL	1060 K—	10000 W
WFBR	1270 K—	500 W
WCBM	1370 K—	250 W

A special arrangement for determining disturbances with greater accuracy and sensitiveness is being built.

The method.

This is extremely simple. The car is driven very slowly along a road which is to be examined. Disurbances will occur frequently. The intensity of the loud speaker is set at a maximum and the local long-distance switch is set for local. Any disturbances that occur have to be considered. Mechanical parts should be checked frequently. Static, noises, or complete failure are recorded.

The most important step in the experiments is the detection of disturbances and their causes. They may be due to man-made equipments or cosmic causes. The first type may be stationary or moving. Every observation should be repeated as often as possible, and the station readjusted by moving the dial. In many cases the station will appear again; the disturbance is then disregarded. If the station does not reappear, outside influences must be sought. Overhead wires (tele-

phone and power), railroad crossings, overhanging trees (especially when wet), road cuts, and the like, may cause stationary disturbances. Motor cars, trains, street cars, etc., may be moving sources of disturbances. It is comparatively easy to distinguish interferences of these types by systematic searching. If any such sources are found, the record of that locality is disregarded.

It may happen that other stations are not disturbed at all, in which case such stations may be used for the experiments. It is impossible, on the other hand, to use two stations in the same region interchangeably, because new constants are introduced with each new station. If one station has been found to give satisfactory results, it is kept thereafter as a reference station.

Fluctuations of the transmitting set can be overcome by repetition of the experiments at close intervals or by continuous observation at one point during a number of hours. The disturbances that were found in these experiments, however, are so strong and abrupt that these fluctuations can be disregarded.

Cosmic disturbances, such as alterations of the magnetic field or electric currents, can be overcome by observations at the same locality during many different days of a week, month, or year. The present experiments were carried on almost one year, during which time all the "dead spots" were checked over and over again. The same locality was visited during many weeks almost daily, always with the same result.

Only if all these sources of possible interference are known or eliminated, can a disturbance be called "absolute" and real. "Dead spots," shown in Fig. 2, were mapped in this manner for station WCAO in Baltimore.

The constants and regularity of these spots led the writer to the belief that they were caused by geologic irregularities in the underground. This view is supported by the close coincidence of the distribution of "dead spots" with geologic structures (compare Figs. 1 and 2).

The phenomena.

If the equipment is moved along any observation line (a road for instance), certain disturbing noises will be heard occasionally. Cracking or fading in the loud speaker are not unusual. Disturbances of a rather annoying kind will often be found in cities, especially below street car wires during

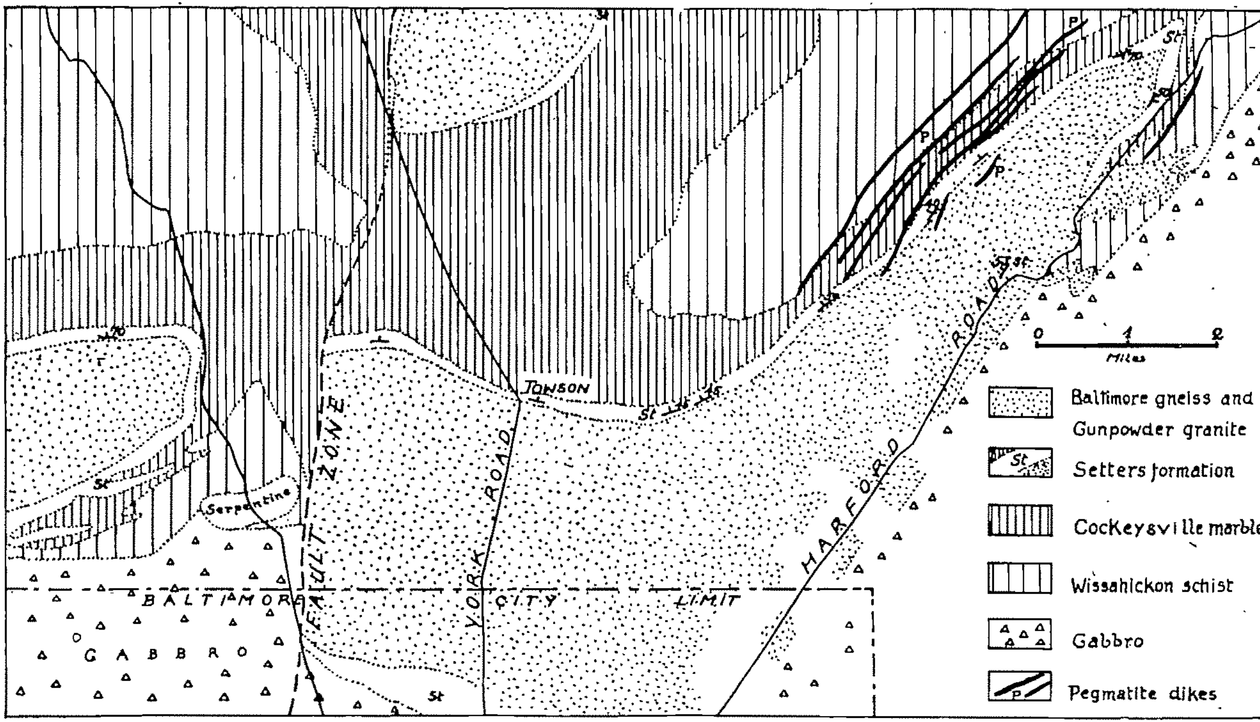

FIG. 1. Simplified geologic map of the region north of Baltimore covered in the radio-reception survey. (After Geologic Map of Baltimore County, 1925.)

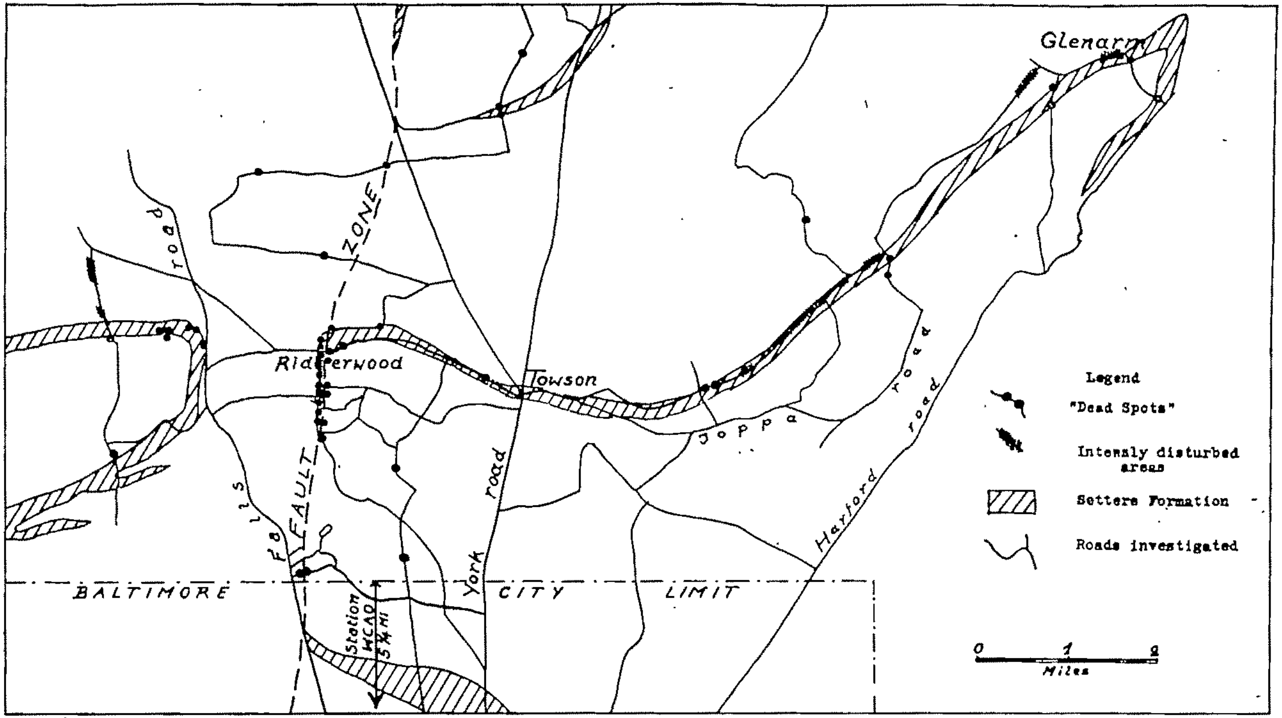

FIG. 2. Same area as Fig. 1, showing the relation between radio-reception disturbances and geologic structure for reference station WCAO.

damp or wet weather. A perfect adjustment of aerial and receiving set eliminates such interferences, however. A well-arranged automobile radio ought to be entirely free from such disturbances. Their cause can easily be found by careful observation of the neighborhood and repeated covering of the locality.

More important are totally "dead spots" at which the reception of certain stations is impossible. The station will disappear entirely and as a rule very abruptly, as if an important wire had broken off or as if the receiver were disconnected. The margins of such zones may be recognized by noises, but the boundary itself is generally sharp. No readjustment with the dial, and very seldom the addition of an amplifier, will recover the "lost station."

The width of such zones varies between 25 and several hundred feet. After the region is passed, the station reappears suddenly. It is then as clear and undisturbed as before.

Perfect reception before and after passing the "dead spot" is essential and the abrupt silence is most striking and astonishing.

Other stations, especially stronger[1] ones, may appear absolutely undisturbed and clear at the same locality. If greater distances from such stronger stations are used, they may likewise be disturbed and in the same manner as weaker stations at closer range. The stronger stations become more useful at greater distances.

In the present case the stations used for comparison were the four Baltimore stations. WCAO was the most suitable, showing "dead spots" most clearly. The others always appeared clear and entirely undisturbed within the region investigated. Station WCAO was therefore used for reference.

The number of "dead spots" and intensely disturbed areas could be very much increased if noises and cracking or fading were also counted. Stations that disappear can occasionally be found again by turning the dial two or three points, *but have to be readjusted after the disturbed area is passed.* This means that the dial adjustment is incorrect only within certain zones.

Further refinement in the method will probably show that these weaker distortions may have the same value as totally "dead spots," and may be due to the same causes.

[1] "Stronger" is used here simply descriptively, without implication as to frequency or power of the station.

The disturbed areas are always found at *exactly the same locality*. They are, furthermore, *constant in time*. No matter at what time of the day, week, month, or year the locality is passed the disturbance will be found at that spot. Only the *intensity* of the disturbance is inconsistent and variable. As a rule the disturbance is more pronounced during the day than during the night. Totally "dead spots," however, are silent at any time.

An example may illustrate the observations:

The road from Glenarm (see Figs. 1 and 2) southward leads uphill for one-third of a mile, rising from 320 to 420 feet elevation. Approximately one-eighth of a mile south of Glenarm a disturbed area is indicated by fading. Complete silence occurs after passing a zone six to eight feet wide. The zone of total silence is almost one hundred feet wide, and the reference station cannot be received either with the amplifier or by readjusting the dial. Beyond the silent zone the reception returns faintly for a short distance and remains fair, disturbed only slightly in spots. One hundred to one hundred and fifty feet below the crest of the hill, a second silent zone is encountered in the same manner and with the same order of magnitude. Southward from this second zone, reception of station WCAO remains perfect for many miles.

A telephone line follows along the west side of the road from Glenarm to the junction with the Harford road. The geologic map, Fig. 1, shows two important boundaries that coincide with the silent zones: the first, south of Glenarm, between the Cockeysville marble and the Setters formation; and the second, near the crest of the hill, between the Setters formation and the Baltimore gneiss. Both contacts dip steeply toward the northwest. Similar examples could be given for other "dead spots" in Fig. 2.

Numerous observations were made in other regions. The results are similar, but a detailed description cannot be given because the observations were only casual, made while traveling from Baltimore to California and back. The dead spots were not observed repeatedly, not more than once or twice. Results cannot be considered satisfactory unless all other sources of interference have been eliminated through *repeated* observations.

Regions that proved to be highly promising are the following: The eastern fault of the Sierra Nevada block, steep faults within the Great Basin region and the Rocky Mountains. The faults that bound the Triassic of Maryland against Appalachian structure give strong indications, but suitable stations

are not always available. Fault zones in northwest Wyoming are described below.

Interpretation of the phenomena.

Interferences by man-made equipments are numerous and widely known and described. Jansky and Bailey[2] have listed a series of disturbing causes of which some may partly explain the phenomena described.

The disturbing factors are:

1. Atmospheric electricity or "static."
2. Operation by man of non-radio electrical devices (inductive interference).
3. Radio broadcast stations operating on the same frequency assignment.
4. Stations operating on frequency assignments different from that used by station wanted.

One of the most important results of the present survey is the close localization of disturbed or silent zones. Their consistency in time and space excludes almost all the possible disturbances by interference.

Moving devices cannot cause strictly local disturbances over a period of time. Other transmitting stations were not noticed during the observations. If they had interfered, however, their interference would not have been so strictly localized. A change in distance of a few hundred feet or less cannot extinguish a perfect reception to complete silence.

A much more serious interference may result from stationary man-made devices such as telephone lines or power transmission lines. Some disturbances are possibly due to such causes. In order to determine the interference of overhead wires, a series of experiments was carried out. A large number of wire crossings over roads were checked against disturbances in reception. A distinction was made between high-power transmission lines, telephone wires, telephone cables, ordinary light and power lines, and wires that serve to support poles or other purposes. Over three hundred such localities were checked. Probable interference was noticed at nine points only. Whether these are due to interference or coincidence cannot be said. But the percentage is so small

[2] Jansky, Jr., C. M., and Bailey, S. L., On the field intensity measurements for the determination of broadcast station coverage. Proc. I. R. E., v. 20, No. 1, 1932.

that such an influence seems unlikely to be the rule. Many hundred other localities were passed but no interference was observed.

Wires that follow certain roads were observed also and disturbances were not found. The roads north of Baltimore are almost all paralleled by such lines and the maps (Figs. 1 and 2) demonstrate the rarity of "dead spots" in relation to such equipment. Several thousand miles were covered along the roads shown in Fig. 2, but only very few and very distinct silent or disturbed zones were found in comparison with the mileage of telephone lines and roads. I am fully convinced that the interference of such wires is negligible. Critical points were eliminated, nevertheless, as a matter of safety.

Serious sources of disturbances, however, are road cuts, overhanging trees, mountain slopes, etc. In case of coincidences of such localities with "dead spots," other parallel and more favorably located roads must be chosen.

Cosmic influences can hardly be held responsible for any of the phenomena described above. Such events as magnetic storms or fluctuations of field intensities by other cosmic causes cannot account for the close localization and restriction of the disturbances to zones of small width. Observations over a long period of time serve to eliminate such variations.

The geologic component.

Figs. 1 and 2 suggest the geologic component as the explanation for the disturbances. The coincidence between particular geologic structures and the occurrence of "dead spots," silent zones, or disturbed areas, is so striking that I believe it conclusive. Almost all the "dead spots" shown in Fig. 2 are situated above a fault or steeply dipping rock boundary of some importance. The ones that cannot be related to such obvious boundaries may represent irregularities *within* one formation, as, for instance, basic inclusions within the Baltimore gneiss or possibly small faults within the Wissahickon schist.

But how can geologic structures exert such influence upon a surface field?

The answer is difficult and probably as yet unknown. Local magnetic disturbances along such zones may be responsible for local distortions of the surface field. Magnetic surveys in connection with radio-reception observations may lead to a

solution of this most interesting problem. It is hoped that further refinement in method or equipment will bring an answer.

Response to different stations.

Only very few stations are suited as reference stations in a given area. Only WCAO furnished satisfactory results in the close vicinity of Baltimore. Its reception is exceptionally good, clear and louder than any other station. The disturbances are more distinct and absolute. The field intensity of WCAO is probably smaller than for the other stations. The latter become more suitable at larger distances, or, in other words, as soon as their field intensity approaches that of station WCAO. It seems as though certain field intensities are best suited for structure observations. This would mean that a concentric belt exists in relation to every station in which observations of this kind are possible. It would account for a number of failures and irregularities. Undoubtedly the reception has to be distinctly weak. The relation between field intensities, frequencies, and power of the station in reference to the reaction to geologic structures and their influences, will be studied in more detail later.

Results—The fault at Riderwood.

The maps, Figs. 1 and 2, show the aerial distribution of "dead spots" and disturbed areas in relation to the geologic underground condition. An accumulation of such spots can be seen at the west end of the Towson anticline. The fault shown on the geologic map of Baltimore County coincides with these disturbances.[8]

It can be seen that "dead spots" are arranged in two distinct lines. The western one is more pronounced than the eastern line, which is partly interrupted. A survey of the topography of this region shows clearly two steps and a distinct ledge between them. The irregular accumulation of disturbances at this locality is connected with the irregular layout of roads along which observations were made and with the geologic conditions at that point.

If more roads crossed the fault to the north and south, it could be more continuously traced in both directions. Such

[8] Map of Baltimore County and Baltimore City showing the geological formations. Maryland Geol. Survey, E. B. Mathews, State Geologist, 1925.

locations were found near Falls Road in the southern extension. Here are two "dead spots" which are very marked and exactly in the direction of the fault, which is exposed at the surface a short distance north of the two spots.

The northern extension is less clear. Two spots are marked, however, one along the projected fault line and another one farther to the west. It may be that the fault branches here into a western branch which dies out toward the north and an eastern branch which continues.

The geologic conditions are unfavorable for mapping faults, because the northern area is underlain by Cockeysville marble and the southern area by gabbro. Neither area gives any marked geological and physical differences on opposite sides of the fault. It is therefore possible that the indications would not be as pronounced as along the boundary between the Baltimore gneiss and the marble at Riderwood.

Other faults, as for instance the fault between the Triassic and the Appalachian structures in Maryland, give good indications at many places. Transmitting stations are not very favorably situated in regard to this fault line and experiments were therefore postponed until the development of the method and instrumental equipment is further advanced.

In conclusion, it may be said that a pronounced fault gives strong and clear indications, provided that suitable stations are available for the experiments.

Rock boundaries.

Boundaries between distinctly different rocks or formations also furnish satisfying results. Fig. 2 shows this clearly. The two very marked contacts between the Setters formation and the Baltimore gneiss and the Cockeysville marble are represented by a comparatively large number of "dead spots" of great sharpness. Other such contacts, not indicated in Fig. 2, are the boundaries between gabbro and schist, gabbro and serpentine or granite, granite and schist, or marble and pegmatite dikes (see Fig. 2, west of Glenarm). Numerous observations were made west and northeast of Baltimore with similar results.

Rock boundaries or contacts furnish therefore the same indications as faults. Geophysical methods do not distinguish between faults and contacts. The distinction must be based on experience and geologic interpretation.

The dip angle.

An interesting and important relation between the dip of geologic structures and the intensity of reception disturbances was observed. The steeper the dip—the better the indication. Flat dipping contacts cause *no disturbance.*

This can be seen in Figs. 1 and 2, for instance between Towson and Glenarm. The northern dip of the Setters formation ranges between 30° and 90°. Low angles prevail near Towson; the dip increases towards the northeast. The number of "dead spots" increases in the same way. No disturbances were observed at the southern flank of the anticline where dips are very gentle.

Assuming that the above-outlined observations have general validity, it will be possible, to a certain extent, to predict dip angles. This is of greatest value for the interpretation of geologic structures. The distinction between low and high-angle faults or thrusts, for instance, may be possible by these very simple measurements.

Observations in Wyoming.

The above results were fully confirmed by observations in the Beartooth and Big Horn region in northwestern Wyoming.

Large fault zones bound the uplifts of northwestern Wyoming on all sides. The displacements are of the order of several thousand feet.

Radio-reception experiments were carried out with stations located at San Francisco; Hollywood; Billings, Mont.; Chicago; and Minneapolis. Good reception from these stations was obtained only during the night. All stations reacted in the same manner as described for WCAO in Baltimore. Observations were made only when reception was best.

On approaching the Beartooth Mountains from the east (Cody-Clark), reception was normal until the fault zone and the region in which all beds are steeply upturned were reached. Absolutely no reception from any station was possible in the neighborhood of the fault zone.

The most interesting results were obtained along the western slope of the Big Horn uplift, especially along the Kane Road from Lovell to Sheridan. This road climbs the mountains, winding considerably and crossing the fault zone at several points. Reception along this road varied between perfection and complete silence during the ascent or descent

of the mountain range. The degree of interference seems to depend upon the distance from the fault zone. As soon as the pre-Cambrian granite core is reached the reception is good.

Interference by man-made equipments is impossible because there are none in this region.

Failures.

Not all geologic disturbances give clear results. This is generally due to the lack of a proper reference station. Not every disturbance has a geologic cause. Great care is necessary in eliminating worthless or invalid indications, caused by other phenomena. We are faced with the same problem that every geophysical method encounters. In measuring elastic constants, gravity differences, electric conductivity, or magnetic disturbances, physical properties are ascertained. The geologic interpretation, as a rule, is obscure and puzzling. A more reliable instrument than the ordinary wireless set and the human ear is necessary for more accurate observations. The result, on the other hand, is clear and, as far as I can see, has shown that there is a close relationship between underground conditions and radio reception. The relations can be used in many ways as an aid in geologic mapping of hidden structures. Further experiments with more refined instruments will, I hope, furnish more data and an improved technique.

Literature.

The available literature was searched carefully, but references to results of the kind here given were not found. A series of very valuable observations and measurements, however, can be used in support of the conclusions of this paper.

Field-intensity measurements for certain stations, for instance Philadelphia, show distortions of the field into asymmetrical figures. These are closely related to river valleys or underground structures.

A selected list of references is:

Barfield, R. H., The attenuation of wireless waves over land. Exp. Wireless (London), 4, pp. 25-30, Jan., 1928.

Barfield, R. H., Deviation of wireless waves at a coastal boundary. Nature (London), p. 35, Jan. 7, 1928. Exp. Wireless, p. 162, March, 1928.

Curtis, Leslie F., Interference in motor car receivers. Proc. Inst. Radio Eng., v. 20, No. 4, 1932.

Espenshied, Lloyd, Radio broadcast coverage of city areas. Journ. A. I. E. E., 46, No. 1, Jan., 1927.

Fritsch, V., Ausbreitung elektromagnetischer Felder laengs Flusslaeufen. Hochfreq. u. Electroakustik, v. 41, 1933.

Jansky, Jr., C. M., Some studies of radio broadcast coverage in the middle west. Proc. I. R. E., v. 16, No. 10, 1928.

Jansky, Jr., C. M., and Bailey, S. L., On the use of field intensity measurements for the determination of broadcast station coverage. Proc. I. R. E., v. 20, No. 1, 1932.

Kirby, S. S., and Norton, K. A., Field intensity measurements at frequencies from 285 to 5400 kilocycles per second. Proc. I. R. E., v. 20, No. 5, 1932.

McIlwain, Knox, and Thompson, W. S., A radio field strength survey of Philadelphia. Proc. I. R. E., v. 16, 1928.

Potter, R. K., and Fries, H. T., Some effect of topography and ground on short wave reception. Proc. I. R. E., v. 20, No. 4, 1932.

Strutt, M. J. O., Zusammenfassender Bericht: Der Einfluss der Erdbodeneigenschaften auf die Ausbreitung elektromagnetischer Wellen. Hochfreq. u. Electroak, v. 39, pp. 177-185, 220-225, 1932.

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SOME VOLCANOES OF SOUTHERN CHILE.

J. B. STONE AND EARL INGERSON.

INTRODUCTION.

During three months in 1929 and 1930 the senior author of this paper, under appointment as a Research Fellow of the Hawaiian Volcano Research Association, was engaged in a reconnaissance of the Chilean volcanoes between the latitudes of 35° 30′ and 41° 30′ south. The object of this investigation was to discover what volcano in this part of Chile would be the most suitable as a location for a volcanological observatory. A detailed report on the reconnaissance has been presented to the Association, but because of delay in its publication some of the results are summarized here. Since the preparation of that report the junior author of this paper has made a petrographic study of the specimens collected, and his results form the second part of the paper.

PART I—DESCRIPTION OF THE VOLCANOES.

Knowledge of the Chilean volcanoes.—Little detailed work has been done on the Chilean volcanoes, and in some cases even accurate reconnaissance notes are lacking. Much of the existing literature was written by German residents of Chile or by visitors from Germany and has appeared in the publications of local scientific societies and of the University of Chile, as well as in a number of German periodicals. The general works of Sapper and von Wolff include data compiled from various sources. The most important works are given below.

Brueggen, J., Bibliografia minera i jeolojica de Chile: Soc. Nac. de Mineria Bol., 1919.

Idem., Bibliografia minera y geologica de Chile (continuacion): Publ. del Cuerpo de Ing. de Minas, Folleto 16, 1927.

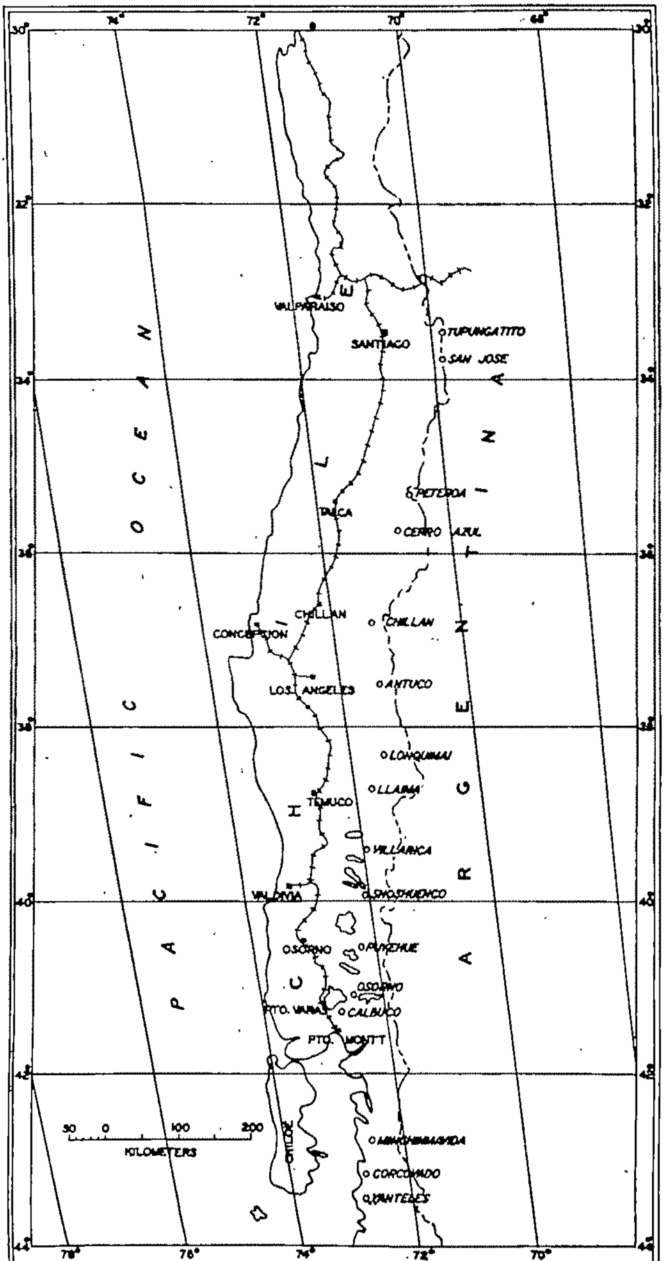
These publications include a fairly complete bibliography of Chilean volcanism. A more complete list is included in the forthcoming report of the present senior author.

Martin, C., Landeskunde von Chile, 2nd ed., L. Friederichsen & Co., Hamburg, 1933.

This work by a long-time resident of Chile gives an excellent description of the country, with many notes on volcanoes that have been freely used by later writers.

Sapper, G., Vulkankunde, Stuttgart, 1927.

Pp. 353-354 give a list of Chilean volcanoes in the region discussed in this paper with abbreviated notes on activity, mostly without reference to the source of information. An earlier work by Sapper (Katalog der geschichtlichen Vulkanausbrueche, Strasburg, 1917) gives references to the literature.



Index map showing the principal volcanoes of Southern Chile. The group including Descabezado Grande and Quizapu adjoins Cerro Azul.

Servicio Sismologico de la Universidad de Chile. The annual bulletins of this organization include brief notes on volcanic activity and occasional longer articles on important eruptions.

von Wolff, F., Der Vulkanismus, Stuttgart, 1929.
Pp. 334-342 give notes on the volcanoes discussed here, agreeing generally with Sapper but in slightly more detail. Pp. 400-401 contain two analyses of rocks from this region. Pp. 420-422 give a short bibliography.

Distribution of the volcanoes.—The south-central part of Chile, though nowhere more than 140 miles wide, is divided topographically into three still narrower strips: the low coast range, the longitudinal valley, and the western slope of the Andes. The volcanoes considered in this paper lie along the western flank of the Andes between the cities of Talca and Puerto Montt, or between 35° 30′ and 41° 30′ south latitude. All of southern Chile slopes toward the south, so that the Andes in this region are not as high as in the latitude of Santiago, where Aconcagua reaches a height of 23,000 feet. Moreover, the volcanoes, instead of being near the crest of the cordillera as they are farther north, stand out in front of the main range and are more easily accessible.

The following list gives all volcanoes between the latitudes of 35° 30′ and 41° 30′ S. that are shown on the map of Chile (scale 1:500,000) issued by the Ministerio de Fomento (Departmento de Tierras y Colonizacion) in 1928. The positions and heights are taken from the same source and do not agree entirely with those given by Sapper and von Wolff. The records of activity are taken mostly from Martin with the addition of some well-substantiated outbreaks. Additional dates are given by Sapper and von Wolff.

Descabezado Chico 3250 m., lat. 35-31 S., long. 70-39 W. Extinct.
Descabezado Grande 3830 m., lat. 35-35 S., long. 70-47 W. Extinct.
Cerro Azul 3810 m., lat. 35-39 S., long. 70-46 W. Extinct.
Quizapu (Cerro del Medio)—between Descabezado Grande and Cerro Azul. Active in 1847, 1912, 1921, 1922, 1923, 1927-1929, 1932.
Las Teguas or San Pedro 3500 m., lat. 35-39 S., long. 70-52 W. No activity recorded.
Chillan 3000 m., lat. 36-50 S., long. 71-30 W. Active in 1750, 1861-1865, and 1906.
(Sapper and von Wolff list the volcano Tromen or Pomahuida. According to von Wolff it is in the Argentine Republic.)
Antuco 2990 m., lat. 37-25 S., long. 71-20 W. Active in 1752 and early 19th century. Last eruption 1863 (von Wolff).
Copahue 3010 m., lat. 37-50 S., long. 71-11 W. No activity recorded.

Callaquen or Callaqui 3090 m., lat. 37-56 S., long. 71-27 W. Smoking in middle of 18th century.
Trolguaca 2780 m., lat. 38-18 S., long. 71-39 W. Extinct.
Lonquimai 2890 m., lat. 38-23 S., long. 71-35 W. Active in 1853, 1887, and 1889.
Llaima 3060 m., lat. 38-42 S., long. 71-44 W. Active in 1852, 1862-66, 1892, 1903, 1912, 1917, 1927, and 1930.
Villarica 2840 m., lat. 39-25 S., long. 71-56 W. Active in 1640, 1876, 1906-1908, and 1920.
Quetrupillan 2360 m., lat. 39-31 S., Long. 71-43 W. Extinct.
Lanin 3740 m., lat. 39-39 S., long. 71-30 W. Long extinct and partly dissected.
Shoshuenco 2360 m., lat. 39-55 S., long. 72-02 W.
El Mocho 2432 m., lat. 39-56 S., long. 72-01 W. Shoshuenco and El Mocho are sometimes known together as the volcano "Riñihue." Reported active in 1907.
(Sapper lists Riñinahue lat. 40-18 S., long. 72-06 W., as active in 1907. This outbreak may be the same as listed here under Riñihue.)
(Sapper and von Wolff mention an explosive eruption followed by a lava flow in 1921 at Los Azufres, lat. 40-28 S., long. 71-53 W.)
Puyehue 2240 m., lat. 40-35 S., long. 72-07 W. (about). Crater near Cerro Cauye was active in 1905 and 1922.
Puntiagudo 2490 m., lat. 40-58 S., long. 72-16 W. Long extinct and deeply dissected. Reported active in 1930 (Boletin Serv. Sism., 1930). Probably an error.
Osorno 2680 m., lat. 41-07 S., long. 72-29 W. Active in 1834-35 and probably later until about 1850.
Calbuco 2015 m., lat. 41-20 S., long. 72-39 W. Active in 1893, 1906 (steaming), 1917, and 1929.

Including Riñinahue and Los Azufres, this list shows 23 volcanoes, of which nine (possibly only eight in case of duplication) have been active since 1900 and of which ten (eleven including Callaquen) have had no recorded outbreaks. The others (Antuco, Lonquimai, and Osorno) were active in the 19th century.

The following paragraphs describe the important volcanoes in slightly more detail. All except Quizapu were visited by the senior author.

Quizapu.—The volcano now called "Quizapu" came into existence on Nov. 27, 1847, by an explosive eruption lasting three days. At the end of that eruption a new cone had been formed where formerly there had been a pass between the extinct volcanoes Descabezado Grande and Cerro Azul. Solfataric emanations were noted from the time of the eruption until 1870, when they ceased, and the cone was not again active until 1912. Since 1912 it has been intermittently active, especially from 1927 to 1929, although the activity ceased completely from a few days before the Talca earthquake of Dec. 1, 1928, until 24 hours afterwards.

On April 10, 1932, after some preliminary signs of activity Quizapu began a violently explosive eruption that lasted two days but had entirely died away by April 21. The column of smoke from the volcano is reported to have reached a height of about 15,000 meters, and ash from the eruption reached Buenos Aires, 1,200 kilometers away, early on April 11. Investigations since the eruption show that much coarse pumice was ejected, and a lava flow probably occurred.[1]

Chillan.—Chillan is reported to have been smoking in 1750 and was in eruption from 1861 to 1865, commencing a few months after a disastrous earthquake near Mendoza in the Argentine Republic and the simultaneous extinguishing of the volcano Antuco (Martin, p. 85). It became active again on Aug. 6, 1906, and remained active for about four months. During this eruption the volcano ejected ash and glowing stones, but there were no lava flows. On Aug. 16, 1906, occurred the terrible earthquake that destroyed most of Valparaiso. In Nov., 1929, two small plumes of steam were seen issuing from the cone built in 1906.

The volcano of Chillan consists of two small cones half a mile apart, standing on a deeply dissected and glaciated platform of ancient (Tertiary?) lavas. There are said to be five or six old craters in the immediate vicinity. The Volcan Nuevo, from which came the eruption of 1906, is a low, broad, black cone. The Volcan Viejo is a similar but less perfect cone farther southeast. Hot-springs, the well-known Termas de Chillan, issue from the older lavas in a little gully. The springs most used give very hot waters, some heavily charged with iron and others smelling and tasting strongly of sulphur. Higher up is a group of small furiously boiling fumaroles issuing from yellowed lavas containing disseminated pyrite. Post-glacial lava flows are seen in the valley below the Termas.

Antuco.—According to Martin, Antuco erupted some time in the early 19th century, and both Sapper and von Wolff list an eruption in 1752 and several others up to 1863. In the "Voyage of the Beagle" Darwin mentions the superstitious belief in Talcahuano that the great earthquake of 1835 which

[1] Serv. Sismol. Univ. Chile, Bol. 19, p. 21, 1927, and Bol. 22, pp. 29-39, 1930. The Boletin for 1930 (published in 1932) contains a most interesting preliminary account of the eruption of 1932. Press dispatches at that time erroneously attributed the eruption to various inactive volcanoes in the vicinity.

destroyed both Talcahuano and Concepcion was the result of the stopping-up of the volcano Antuco by an Indian witch two years previously. The present inhabitants of the region know of no eruption of Antuco. The volcano was steaming slightly in Nov., 1929, and some bluish vapor was seen in the north part of the summit crater. There are hot spots around the rim of the crater, and Martin points out that the cone in spite of its height has little or no permanent snow.

The region around Antuco shows a long and complex history of volcanism. A basement of granitic and metamorphic rocks is seen between the village of Antuco and the volcano. Above this basement comes the great pile of interbedded lava flows and pyroclastic rocks cut by a few dikes that forms the Sierra Velluda. This range is deeply eroded and glaciated, so that it no longer presents the outward shape of a volcano. Much younger than these oldest volcanics but apparently older than the cone of Antuco is the great accumulation of ejecta in the valley of the Rio de la Laja. Explosive craters probably existed in the northwest slope of the Antuco mass, and a segment of an old rim can be seen northeast of the present cone.

The cone of Antuco is largely covered (as far as could be seen with much snow on the ground) by aa flows, many of which originated near the summit crater. The crater is now occupied by rough aa, which overflowed through a break in the east rim. A horse-shoe shaped cone low down on the west slope was the source of the freshest flow seen. All of the flows and fragments examined in the field were basalts, mostly containing olivine. A common type is a vesicular basalt with abundant plagioclase phenocrysts and a few olivine phenocrysts. The old flows of the Sierra Velluda were not seen close at hand except as they are represented by fragments in the later pyroclastics.

Llaima.—According to Martin, Llaima was active from 1862 to 1866 and emitted high smoke clouds in 1864. Other eruptions took place in 1852 and 1892,[2] and other dates are given by Sapper and von Wolff. On May 12, 1903, another eruption occurred in which lava flows were poured out that could be seen from Temuco. This eruption lasted two days and changed the shape of the volcano (Martin). Llaima was active also in 1912 and 1917.

[2] Serv. Sismol., Univ. Chile, Bol. 22, p. 16, 1930.

In 1927 Llaima was active from Oct. 5 to 8, and again from Nov. 27 to Dec. 5.[3] According to local residents the southeast crater was the more active, although the northwest cone smoked. The eruptions built up the southeast cone noticeably. At night fountains of fire and incandescent rocks were thrown into the air, and a "river of fire" ran down the south slope. The senior author could find no sign of a recent lava flow under the snow on the southern foot of the summit cone, but there may have been a flow farther around to the east. Two or three inches of fresh black scoriae lay on the glacial ice on the south slope. It may have come from the summit crater or from a fountain at the source of a flow. During the eruption of 1927 ash and lapilli up to about 2 cm. in diameter fell on the north side of the volcano, three to five miles from the summit. Earthquakes were felt at the same place.

In December, 1929, Llaima was emitting dense white smoke from both summit craters. An eruption of "lava" and ash occurred in July and August, 1930.[4] No plutonic or metamorphic rocks were seen near Llaima. The double cone of the volcano stands on a wide platform composed largely of aa flows. One large cinder cone at the west edge of this platform consists of black or locally red basaltic scoriae and many broken bombs. A line of large old cones extends off to the northeast, and other cones were seen to the southeast. Where the surface of the volcanic platform is not covered by aa flows, it has a covering of ejected blocks, pieces of bombs, ash, and black scoriaceous pumice. The glaciers that now cap the volcano formerly extended lower down and have left polished flows on the northwest slope and moraines on the southwest to mark their former position. All lavas seen or collected on Llaima are basalts. Those with recognizable phenocrysts generally show feldspar and olivine.

Villarica.—Villarica erupted lava in 1640, and in 1876 its glow could be seen far over the land and even from the ocean (Martin). It was active from 1906 to 1908, during which time there were several explosive eruptions. On Oct. 31, 1908, a strong ash eruption melted the snow and glacial ice on the

[3] Serv. Sismol., Univ. Chile, Bol. 19, pp. 27, 29, 32, 1927.

[4] Serv. Sismol., Univ. Chile, Bol. 22, pp. 16, 18, 1930. The word "lava" is popularly used in Chile for fragmental as well as fluid volcanic products. Unless flows are specifically mentioned in press dispatches, their occurrence should not be assumed from the word "lava."

east side of the cone and caused an avalanche or flood that reached Lake Villarica at Pucon (von Wolff and local residents).

In 1915 and until 1918 a glow could be seen over the crater at night, and after the glow disappeared there was white "smoke" or steam. In 1918 the volcano had a deep, open summit crater. On Dec. 9, 1920, a sharp earthquake was felt at ranches on the north slope of the cone. Other shocks followed, and on the next day the volcano began a series of explosions that lasted about 36 hours. Little or no material was thrown from the crater. In 1921 the summit crater was nearly all filled with broken rock. In 1929, when seen by the senior author, there was again an open crater 200 or 250 feet across and at least 150 feet deep, from which rose a thin cloud of fume containing sulphur dioxide. The outer rim of the crater consisted of reddened or bleached slaggy lava.

Lake Villarica, like most of the big lakes of southern Chile, was formed by glaciers rising in the cordillera to the east. The west shore of the lake and the surrounding country is of moraine and outwash material. The east shore and the little island in the middle of the lake are of ice-polished volcanic rocks. Some wooded hills south and southeast of Pucon are also composed of volcanic rocks, probably of the same preglacial series.

The route up the volcano from the north follows a steep-sided valley floored by fairly recent flows and volcanic sands. The shape of this valley strongly suggests a radial fault trough. Most of the surface of the cone between timber line and snow line is covered by aa flows, but there are a few rough pahoehoe flows. Basalts with abundant and conspicuous feldspar phenocrysts are common, and some unusual glassy flows were seen.

Osorno.—In the "Voyage of the Beagle" under the date of Nov. 26, 1834, Darwin notes that Osorno "was spouting out volumes of smoke," and on the night of Jan. 19, 1835, he observed an eruption. Since about 1850, however, no activity is known, and for many years the great ice mass filling the summit crater has been much the same.

Very few lava flows are seen on the surface of Osorno, but instead it is covered by harsh pumice and angular gravels, partly thrown out by explosive eruptions and partly formed by erosion. At the west foot of the volcano on the lake shore

just north of Ensenada there is an area of fairly fresh aa flows of different ages, as is shown by the size of the trees growing on them. These flows represent one of the last phases of activity and come from the lower part of a radial rift zone on the southwest slope, the rift being marked up to the edge of the ice cap by many large cinder and spatter cones. Not all these cones were the sources of flows, but most are covered only by basaltic cinders and a few bombs. A few other inconspicuous cones are scattered over the whole mountain but scarcely mar its symmetry.

The top third of Osorno is completely covered by a cap of ice, except in two places where a small bit of the crater's rim is exposed. The rim is of black slaggy lava. The width of the crater is between 250 and 300 meters. A small remnant of heat in the crater keeps the two outcrops bare and keeps open caves extending steeply down under the edges of the great heap of ice in the crater.

Calbuco.—Darwin noted that Calbuco was emitting little jets of steam in 1834, and the volcano is reported to have been active in the first half of the 19th century. For forty years or more before 1893, the volcano was so quiet that snow filled its crater, and a glacier lay on the south slope. In 1893, however, there were ash eruptions from January to November. The renewed volcanic activity accompanied by heavy rains melted the snow and ice, and caused great floods and landslides. Forests were set on fire by "masses of glowing lava" (Martin). In 1906 steam clouds still rose at times from the crater. In 1911 Calbuco had a circular, steep-walled crater one kilometer across with a cone in the middle (von Wolff). In April, 1917, there was a brief ash eruption.

On Jan. 6, 1929, there was another brief explosive eruption. After preliminary rumblings a great flame shot from the summit crater and was followed by an immense cloud of ash accompanied by much lightning. A light earthquake was felt at about the same time. The ash drifted far to the east into the Argentine Republic. On the north slope of the volcano brush and small trees were killed and slightly charred by a downward blast of ash. As in 1893 floods were caused by the melting of snow and ice.

In January, 1930, the senior author found that the eruption of the previous year had left a funnel-shaped pit at the east

end of a larger and older summit crater. Thick white fume was escaping from several places in the talus slopes of the pit.

The later history of Calbuco has been dominantly one of explosive eruptions. Few flows are seen anywhere and no long ones on the surface of the volcano. Instead, the deep cut-bank ravines show accumulations of unconsolidated, angular volcanic gravels many feet thick. The few flows exposed are thick, columnar-jointed masses. A short flow near the crater, doubtfully attributed to the eruption of 1917, is broken semi-aa.

An explosive history older than the present cone of Calbuco is recorded in the inward-facing cliff bounding the volcano on the east. This cliff is made up almost entirely of bedded pyroclastics and is probably due to a fault like those that formed the bounding cliffs on the south of the volcano.

The crater of 1929 is a deep pit with steep rock walls capped by angular gravel. In 1930 it had an estimated diameter of 250 to 300 meters and a depth of at least 100 meters (distances of this kind are hard to estimate correctly). There is evidence that both explosion and subsidence took part in its formation.

The lavas of Calbuco were classified in the field as basalts, although some specimens are quite light-colored. Many of the pieces from flows are characterized by the presence of many small, apparently broken crystals.

General features of the volcanoes.—The volcanoes of southern Chile belong to a type that combines explosive eruptions with lava flows, although explosive activity predominates. In size they cannot compare with some of the giant volcanoes of the world, but Osorno rises 8,560 feet above Lake Llanquihue, and both Llaima and Villarica are about as high. Their shape, due to a predominance of explosive eruptions from a central vent, tends to be steeply conical with concave slopes. Villarica, Osorno, and Antuco, especially when viewed from certain directions, are beautifully symmetrical.

The Chilean volcanoes seem to be approaching extinction. Many are long dead and already partly destroyed by erosion, others show only by their undissected form and emission of steam that they are still potentially active, and only a few have been active in the last century. For one of these volcanoes to have been active more than once or twice in twenty years is

most unusual; and in the area under consideration only Quizapu and Llaima have been so active since 1900. On the other hand, the geological record, which is especially well exposed at Antuco and Calbuco, shows that during an earlier epoch eruptions of much greater violence took place. The extent and thickness of the older volcanic deposits point not only to much greater eruptions but also to more frequent ones.

The modern eruptions for which there are any data have mostly been short and quite mild. They have at times been accompanied by earthquakes but only feeble and very local ones, although an apparent connection has several times been noticed between the outbreak of a volcano and one of the destructive earthquakes which occur so frequently a little farther north. The most dangerous feature of the eruptions is the possibility of sudden floods caused by the melting of the cover of ice and snow which caps most of the volcanoes. Little damage to human beings has been done by ash falls, and none, so far as known, by lava flows.

Lava flows have not been common during modern eruptions, but lava has commonly been present in the craters, as is shown by the mention of the glow and "columns of fire" in the accounts of the eruptions. Bombs and fragments of bombs are abundant on the slopes of Llaima and Osorno, and basaltic scoriae were produced at Llaima in 1927 and at Puyehue in 1922. Much pumice was erupted by Quizapu in 1932. No bombs were found among the ejecta of the eruption of Calbuco in 1929, and the ash of that eruption contains very little fresh glass. The craters of Antuco, Villarica, Osorno, and Calbuco are partly surrounded by rims of spattered slaggy lava. The eruptions appear to be of magmatic origin.

The rocks of the southern Chilean volcanoes were all classified in the field as olivine-poor basalts. Quartz was not found in a single specimen, including not only those collected but also many more examined in the field. Biotite was also completely absent, as was hornblende with the doubtful exception of one fragment from the older tuffs of Antuco. Feldspar phenocrysts occur in all specimens, except in a few almost wholly glassy lavas, and olivine was found with the hand lens in nearly all. Some of the lavas contain hypersthene. The textures range from glassy to almost wholly crystalline. The presence of a remarkable proportion of large plagioclase phenocrysts in some flows is notable. Von Wolff includes the vol-

canoes discussed here in an outer row of volcanoes extending from Patagonia to the vicinity of Quizapu. These volcanoes, he says, have basic andesite lavas approaching basalts. They contrast with an inner row of volcanoes farther north that have rhyolite lavas.[5]

The lavas occur as flows, as fragmental products derived from older flows, and to a smaller extent as scoriae and bombs. By far the most common variety of flow is typical aa. Not a single typical pahoehoe flow was seen, although a very rough variety of pahoehoe was noted in one flow on the north side of Villarica. Some old flows of Osorno and Calbuco now appear as columnar lavas and may originally have had pahoehoe tops. Consideration of the southern Chilean volcanoes as a group and also of the local geology of individual volcanoes shows that activity has declined greatly from a maximum, probably in the Tertiary, and that the present-day activity is but the dying flicker of this epoch of volcanism in the Chilean Andes. Further points of interest in this connection are the predominance of explosive eruptions at these basaltic volcanoes, the presence of many large feldspar phenocrysts in some flows, and the almost universal development of aa lava.

Whether or not the character of the eruptions has changed since the period of greatest activity could not be determined by the reconnaissance studies made by the senior author. Lava flows are interbedded with the oldest tuffs, but they are also found on the surface of most of the modern cones, although few have been erupted in historic time. Likewise ejected blocks and ashes are found in the deposits of all ages. If any change can be recognized on the basis of this reconnaissance, it is in the direction of a greater proportion of explosion to lava production. The infrequent and rather insignificant recent eruptions suggest that the volcanoes of southern Chile are connected only with small magma reservoirs. In these small residual reservoirs the magma has been cooling for a long period and may be expected to be in a partially crystalline state. This crystallinity is shown by the large proportion of intratelluric crystals appearing as phenocrysts in some of the recent flows. Advancing crystallinity may have so increased the viscosity of the magmas and the resulting lavas that the eruptions are increasingly explosive. The explosive nature of vol-

[5] Der Vulkanismus, p. 340, 1929.

canoes having stiff siliceous lavas is often remarked, but it seems possible that through advancing crystallization basaltic lavas may reach a similar stage of viscosity and so favor explosive eruptions.

When poured out on the surface, the partly crystalline magmas produce aa flows. It has been shown that if crystallization be promoted, lavas tend to assume the aa structure.[6] In the case of the Chilean volcanoes crystallization has been able to proceed under conditions of long cooling in a magma reservoir. In the case of the long flows of Mauna Loa, in Hawaii, that issued as pahoehoe, crystallization proceeded on the surface so that at a distance from its source the lava turned to aa. Intra-telluric crystallization is not suggested as a universal explanation of aa structure; it is only one of the ways in which crystallization may become so advanced that a lava on eruption will take the aa form.

Earthquakes.—Severe earthquakes are not as common in the part of Chile between Talca and Puerto Montt as they are farther north near Santiago or still farther north near Copiapo, but they are by no means unknown in the northern portion. Talca was largely destroyed and suffered the loss of many lives in December, 1928, and other disastrous quakes are recorded. In the southern portion, however, severe quakes are rarer although there have been several on the island of Chiloe. Feeble tremors have accompanied some of the volcanic eruptions.

PART II—PETROGRAPHY OF THE LAVAS.

Practically all of the fifty specimens examined and described below are fresh lavas from the volcanoes of southern Chile. Most are from recent flows, but some specimens are from ejected fragments. Only half of the rocks were examined microscopically, as it is evident from the hand specimens that many of them are practically identical types. Microscopic and megascopic descriptions are combined below in an attempt to give a brief picture of the character of the rocks of the volcanoes from which specimens were collected.

The lavas are predominantly olivine-bearing basalts ranging

[6] Emerson, O. H., The formation of aa and pahoehoe: this Journal, vol. 12, pp. 109-114, 1926.

from glassy and aphanitic specimens to moderately vesicular lavas with vesicles up to 1 cm. in diameter and phenocrysts of feldspar up to 5 mm. in diameter. The lavas of Calbuco constitute a notable exception to this generalized picture in that they all contain hypersthene, and olivine is practically absent from them.

Chillan.—No thin sections of the rocks from Chillan were studied. The hand specimens are olivine-poor basalts which range from aphanitic and glassy-vesicular to porphyritic. The porphyritic specimens are slightly vesicular, and the phenocrysts of feldspar range up to 3 or 4 mm. in diameter. The porphyritic rocks have been considerably altered.

Antuco.—The rocks from Antuco are fresh basaltic lavas from recent aa flows and range in color from dark gray to black. They vary somewhat in vesicularity and texture, ranging from aphanitic, slightly vesicular lavas to varieties that are moderately vesicular with glassy groundmass. These variations are probably due to local variations of conditions attendant upon extrusion.

Two specimens were studied microscopically. Both are olivine basalts with abundant phenocrysts of labradorite and a few of olivine. The lighter-colored of the two specimens has a pilotaxitic groundmass in which the microlites of feldspar show a decided fluxion arrangement. There are smaller amounts of augite, magnetite, and glass. The groundmass of the darker lava is composed almost wholly of a brown basaltic glass which is rendered almost opaque by fine inclusions, probably of oxides of iron.

The phenocrysts of these rocks are almost certainly of intratelluric origin; at least they had formed before actual extrusion from the vent took place. However, the fluxion arrangement of the feldspar microlites of the one and the large amount of glass in the groundmass of the other indicate that the magma was still moderately fluid as extrusion took place.

Llaima.—The rocks from Llaima are very much like those from Antuco. They may be characterized in general as dark-gray, fine-grained, slightly vesicular olivine-bearing basalts. They range in color from light gray to almost black and in structure from aphanitic rocks in which the vesicles are barely visible to moderately vesicular lavas in which the vesicles aver-

age some 2 mm. in diameter and reach a maximum size of about 1 cm. The vesicularity ranges up to about 10 per cent.

Four thin sections of the Llaima lavas from flows and ejected fragments were studied and showed about the same variations as did the specimens from Antuco. The textures vary from intersertal to seriate porphyritic with a hyalopilitic groundmass. These textural differences are doubtless due to different conditions of extrusion and solidification, as the mineral compositions of the various specimens indicate that they are very similar chemically.

Phenocrysts are practically absent from one of the specimens and reach a maximum of 20 per cent in another one. The maximum size of the phenocrysts ranges from less than 1 mm. to about 4 mm. In the few specimens studied there seems to be no definite relation between the size of the phenocrysts and their abundance or the degree of vesicularity.

The phenocrysts consist predominantly of labradorite; olivine makes up 20 per cent of the phenocrysts of one specimen, but is almost entirely absent in some of the others. The groundmass is composed of 30 to 50 per cent labradorite, 5 to 20 per cent augite, and minor amounts of magnetite and olivine in a glassy basis.

Villarica.—The basalts from Villarica are practically identical with those from Llaima. They show the same variations in color, texture, and structure, but are perhaps somewhat lower in olivine.

In addition to the basalts there are three glassy flow rocks from Villarica. Only one of these seemed to have enough phenocrysts to make a microscopic examination worth while. This specimen is a distinctly and evenly banded rock: red-brown bands alternate with black vitreous ones. The individual bands range up to 6 mm. in thickness. A few small crystals of feldspar are visible. The vesicles, which are drawn out into lens-shaped holes, are partly filled with a clear glassy mineral.

Under the microscope the feldspar crystals are seen to be aligned perfectly with the banding. They are andesine and make up about 5 per cent of the rock. The vesicles make up another 5 per cent and are mostly filled with a clear isotropic mineral whose index as determined from crushed material from the hand specimen is 1.48. It appears to be cristobalite.

Most of the rock is composed of glass in which are embedded innumerable hair-like crystals which are probably feldspar and pyroxene. The rock is a banded andesitic vitrophyre. These flow rocks probably represent extrusions of a different age from the basalts, as they differ from them not only in texture, but also in composition. (Both vitrophyre and basalt specimens came from surface flows on the north side of the volcanic cone. J. B. S.)

Puyehue.—Only one specimen was collected near Puyehue. It is an older rock from a quarry near the Termas de Puyehue. It is dark green and aphanitic and shows no exceptional features. The microscope shows this rock to be composed largely of microlites of labradorite which have a subdued fluxional arrangement. The interspaces are filled with augite, iron ore, and glass. There are a few remnants of olivine, which in some places have been altered to serpentine and in others to serpentine, opal, and chalcedony. This rock would be classified as an altered olivine-bearing basalt.

Osorno.—The lavas from Osorno merit no detailed description as they are ordinary olivine-bearing basalts and are very much like those from Villarica and Llaima. They range from medium gray to black and from slightly to moderately vesicular. The microscope showed all of the specimens of which thin sections were available to be fresh olivine-bearing basalts having the same textures as those of the lavas from Llaima.

Von Wolff lists an analysis of a specimen from Osorno by H. Bruhns that he classes as augite andesite. It contains 54.58 per cent silica.[7]

Calbuco.—The lavas from Calbuco do not differ radically in general appearance from those from the other volcanoes. They range in color from light-gray to almost black and in texture from aphanitic to slightly vesicular-porphyritic. The chief difference between the Calbuco lavas and the others studied is that hypersthene is the dominant ferromagnesian mineral in the Calbuco suite. The hypersthene ranges up to 5 per cent and there are smaller amounts of augite and magnetite; most of the specimens contain a very little olivine in addition. Feldspar and glass complete the list of components,

[7] Der Vulkanismus, pp. 400–401, 1929.

and the feldspar usually composes more than half of the entire rock.

The lighter-colored lavas have a decided andesitic appearance, but in view of the fact that the plagioclase is labradorite and that they contain some olivine, they must be called olivine-bearing hypersthene basalts. The lighter-colored ones can be called leuco-basalts. Von Wolff states that the lava of Calbuco is a rough trachytic hypersthene andesite with 54.07 per cent silica, composed of labradorite-bytownite, olivine, hypersthene, augite, and magnetite.[8]

In addition to the lavas some specimens from ejected blocks on the rim of the crater of Calbuco were studied. These rocks are light gray and when examined casually they look very much like the leuco-basalts. However, when examined under the microscope, they are found to be composed largely of crystals which seem to have been crowded together with such force as to shatter one another. There was probably a "crystal mush" in the throat of the volcano and an explosion perhaps literally pushed the material up onto the rim of the crater.

These specimens contain practically the same components as do the associated basalts, the chief difference being the lower content of oxides of iron and glass in the former. The amount of glass varies from almost nil in the more massive and less porous specimens to one-third of the rock in the more "pumiceous" ones. Labradorite and glass together make up, on the average, 90 per cent of these rocks. In those in which the glass is very low, the labradorite makes up practically the entire 90 per cent. Hypersthene averages 5 per cent and augite and magnetite complete the list. No olivine could be found in these rocks.

Pumice is defined as a "highly vesicular glass." These blocks are by no means entirely glassy, but their structure is decidedly like that of pumice. They were probably produced by the same process that produces pumice, but from a magma that had already largely crystallized rather than from an entirely liquid magma. Perhaps the term "crystal pumice" is an appropriate one to apply to them. The very high content of labradorite in some of these rocks suggests that extreme crystal sorting may have taken place locally in the throat of the volcano.

[8] Op. cit., p. 337.

Some of the ash that was expelled during the 1929 eruption of Calbuco was studied with the microscope. It was found to be composed largely of fragments of crystals of labradorite and fragments of material rendered almost opaque by included oxides of iron. This material probably represents fragments of pre-existing rocks, or material that had solidified in the throat of the volcano before the eruption. A very little of a clear light-yellow glass of index 1.51 plus was discerned. This clear glass was probably formed at the time of the eruption and indicates that there was perhaps some fluid material in the crater at that time. The ash also contains numerous fragments and some well-formed crystals of hypersthene, as well as smaller amounts of crystals and fragments of augite and magnetite. No olivine crystals were observed in the ash.

An analysis by A. Beutell of ash from the eruption of Calbuco in 1893 is listed by von Wolff as hypersthene andesite. It shows 58.58 per cent silica.[9]

A study of the conditions that give rise to hypersthene at Calbuco in preference to the more common ferromagnesian minerals at the other volcanoes should be among the most interesting problems for a volcanological observatory.

Intrusive rock.—One specimen was examined from an intrusive mass in the older complex on which the lavas of Calbuco and Osorno rest. It was collected from a road cut on the south side of Lake Llanquihue. The hand specimen is moderately coarsely crystalline, the grains averaging 2 mm. in diameter. It is composed largely of quartz and feldspar, but there is enough dark mineral present to give it a light-gray color as seen from a distance.

Under the microscope the rock is seen to have about the following composition:

Plagioclase	40%
Quartz	30%
Potassium feldspar	15%
Biotite and hornblende	9%
Magnetite, apatite, and secondary minerals	6%

Much of the plagioclase is zoned, but it has an average composition of andesine. The rock is a granodiorite according to the Johannsen classification. The ferromagnesian minerals have been chloritized with the development of a little

[9] Op. cit., pp. 400-401.

secondary magnetite. The feldspars have been slightly kaolinized and a little secondary carbonate has been developed. The quartz shows no trace of strain shadows.

Summary.—The lavas that were collected from the Chilean volcanoes may be characterized as olivine-bearing basalts. They show the common features of such lava flows and are of a fairly uniform character. They range in color from light-gray to black and in texture from almost wholly vitreous to porphyritic vesicular with microcrystalline groundmass. The lavas of Calbuco are exceptional in that hypersthene is the chief ferromagnesian constituent and olivine is almost entirely absent.

PUEBLO, COLO.,
AND
NEW HAVEN, CONN.

THE DUSTFALL OF DECEMBER 15-16, 1933.

L. R. PAGE AND R. W. CHAPMAN.

At Hanover, New Hampshire, and at other points in northern New England, on the morning of December 16, 1933, a yellowish icy crust covered the snow that had fallen the preceding day. Dr. H. M. Bannerman, of the Department of Geology at Dartmouth College, was one of the first to notice this colored crust, and he subjected it to a microscopic examination. This examination showed that the yellowish color was due to the presence of appreciable quantities of atmospheric dust. Fragments of volcanic glass showed that the dust was not of local origin. At his suggestion Mr. L. R. Page collected a number of samples of this dust and studied it in more detail. On learning that Mr. R. W. Chapman of Harvard University was making a study of the same dustfall it was decided to collaborate in the publication of data on this subject.

GENERAL NATURE OF THE DUSTFALL.

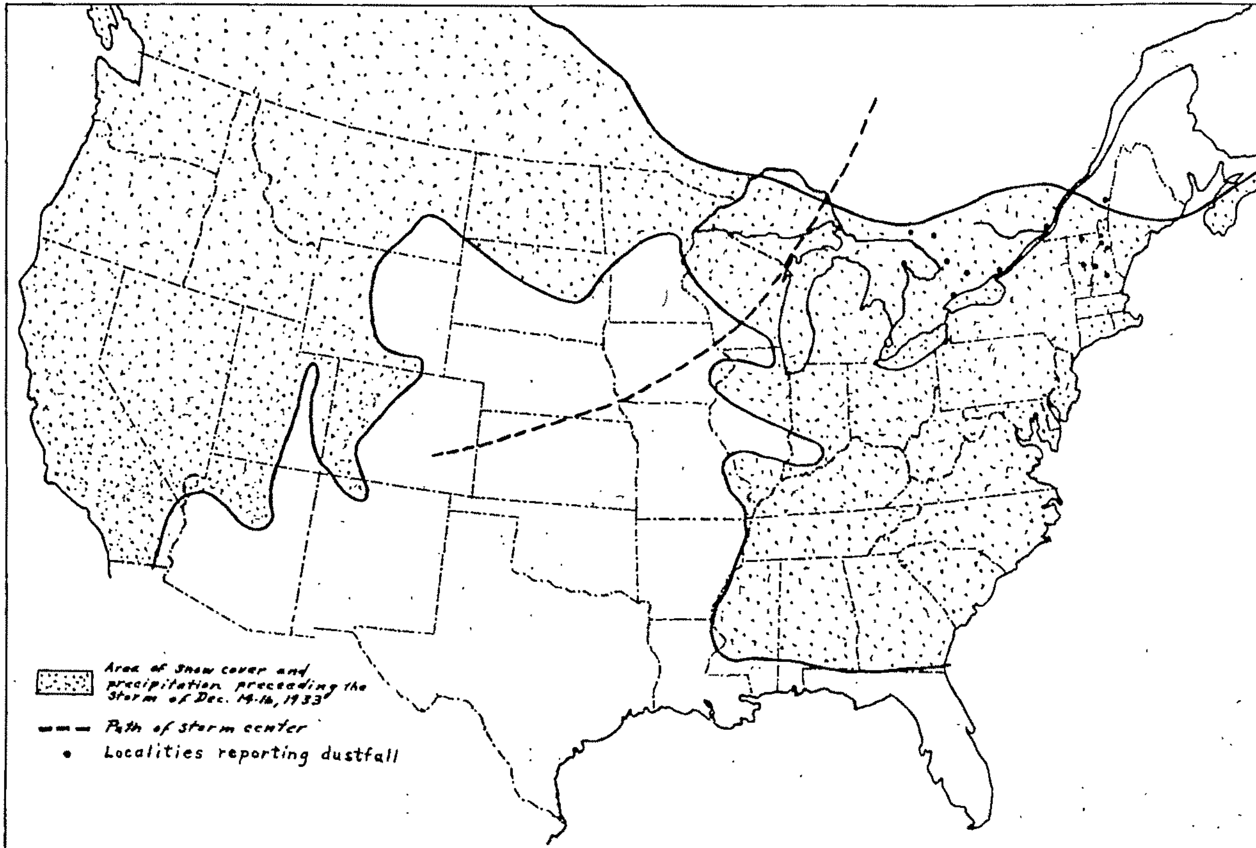
The fall of dust in Hanover, New Hampshire, was accompanied by rain and hail. Inquiries have since shown that the same storm which was accompanied by the dustfall at Hanover, New Hampshire, was also accompanied by dustfalls from Sault St. Marie, Michigan, to Beauceville, Quebec. According to Mr. C. D. Ferguson of Copper Cliff, Ontario, dust-colored snow and sleet started to fall during the mid-forenoon of December 15. During the late afternoon of the same day it was noted at Ottawa, Ontario. In New Hampshire, Vermont, and some parts of Quebec, the dustfall started sometime between 9:30 P. M. on the fifteenth and the morning of the sixteenth. At Laconia, New Hampshire, the main amount of dust had fallen before 3:30 A. M. of the sixteenth. There is a little evidence to show that at Hanover, New Hampshire, small amounts of dust continued to settle out of the atmosphere until the eighteenth of December.

The color of the icy crust varied from place to place, depending on the amount and kind of dust particles present. At Montreal, Quebec, it was brown; at Laconia, New Hampshire, red; and at Hanover, New Hampshire, yellow. Samples of the dust when dried varied in color from black to reddish

brown. The specimens that were black derived their color from the presence of large amounts of organic material, while the reddish colors were due to the presence of large amounts of iron oxide, present as a coating on the dust particles.

The weather conditions that existed at the time of the dustfall were rather unusual. At Hanover, New Hampshire, the temperature on the morning of the fifteenth was about 0° F. but moderated during the forenoon. At noon it started to snow and continued until 3:30 P. M., when rain and hail began to fall. The temperature at this time was about 15° F. and the rain formed an icy coating on surfaces that it struck. At about 7:00 P. M. the rain and hail abated, to increase again at about 11:00 P. M. At daylight on the morning of the sixteenth the storm was over and the snow of the preceding day was covered with the colored crust. During the day a peculiar haze was present in the sky. That evening the presence of a very heavy fog, made up of minute ice particles, caused very hazardous driving conditions since it accumulated on the windshields of automobiles as a thick coating of white frost. This frost was sufficiently gritty to leave a good polish on the windshield after it had been wiped off. If melted and allowed to evaporate, a reddish residue was left. The following day, December 17, although the sun could be seen through the haze, the sky did not clear until just before sunset. The presence of the haze suggests that the dust continued to settle out of the atmosphere in small amounts during this time. Before and after the dust storm the sun's rays were highly refracted, causing very unusual sunsets, for winter, and indicating that dust was present in extraordinary amounts in the upper atmosphere.

A memorandum of this dustfall prepared by Mr. Thomson of the Department of Marine, Meteorological Service of Canada, Toronto, Ontario, contains the following account of the storm: "Mr. C. D. Ferguson, Copper Cliff, Ont., has given the following account of the dustfall occurring there. 'On December 15th last a hail and snow storm commenced about 8:00 A. M. and continued off and on until shortly after 12:00 noon. Up until past mid-forenoon the rain and hail were white and clean. There then fell a very thin layer of mud-covered snow and hail. The hail which was in fair sized ice crystals was distinctly stained a clay or mud color. Also the layer of colored snow was distinct and not intermingled with the clear newly fallen hail and snow beneath.' "


Area of snow cover and precipitation preceeding the Storm of Dec. 14-16, 1933
Path of storm center
Localities reporting dustfall

All reports of the storm which brought the dust are similar to those given above in that they show the dust was definitely brought out of the upper atmosphere along with rain and hail during the later stages of the storm.

AREA OF DUSTFALL.

In determining the area covered by this dustfall, press reports, direct observations, and data furnished by various individuals were used. The area covered in New Hampshire was noted to a large extent by direct observation of the authors. Mr. L. K. Perley of Laconia, New Hampshire, sent a report of the storm to Mr. Willard Fisher of the Harvard University Observatory, Cambridge, Massachusetts. This data has been used. Mr. J. Patterson, Director of the Meteorological Service of Canada at Toronto, Ontario, furnished us with a memorandum of the storm which had been prepared by Mr. Thomson of that department. This gave reports of the dust from Ottawa, Copper Cliff, Sudbury, North Bay, Sault St. Marie, Sparrow Lake, Muskoka, Ontario, and Montreal and Beauceville, Quebec. The United States Weather Bureau furnished temperature data that also aided in determining the area of the dustfall, although none of its observers reported it. Further information was furnished by Professor C. F. Brooks of the Blue Hill Observatory, Milton, Massachusetts, and by Mr. Wilson Reed, Jr., of the U. S. Weather Bureau, Cleveland, Ohio. Mr. Reed reported that dusty conditions were noticed as far west as southern Illinois and western Indiana.

In addition, the following persons have contributed valuable information in regard to the area covered by the dust: Dr. W. J. Fisher, Harvard Observatory, Cambridge, Massachusetts; Rev. Arthur B. Crichton, Newport, Vermont; Dr. E. A. Cramton, St. Johnsbury, Vermont; Miss Frances Goddard, Colebrook, New Hampshire; Mr. A. M. Bean, Errol, New Hampshire; Mr. R. M. Hutchins, North Stratford, New Hampshire; Miss Marion Leavitt, Meredith, New Hampshire; Mr. Don W. Stevens, and Mr. J. L. Mills, Lyman Falls, New Hampshire.

The localities from which dust was reported are indicated on the accompanying map by large dots. Although no dust was reported from Boston, Massachusetts; New Haven, Connecticut; Pawtucket, Rhode Island, or Portland, Maine, rain

and sleet at a temperature of 15° were reported, suggesting that dust fell in these places but was unnoticed because of smoke or lack of clean snow cover.

TOTAL QUANTITY OF DUST.

Measured areas of the colored crust were taken from Groveton and Hanover, New Hampshire, and the weight of dust per square foot was determined. R. W. Chapman collected a sample from four square feet of surface at Groveton, New Hampshire, and determined the total weight of dust to be 0.260 gram, or 65 milligrams per square foot.

At Hanover four separate samples of the crust, one foot square, were taken at distances of from one to three miles from the center of town. The total weight of dust was determined in each of these samples by filtering them in a Gooch filter and drying at 100° C. before weighing. The organic matter was driven off by burning and the weight of both the organic and inorganic material was thus determined. The dust was black in color before burning due to organic matter but was reddish brown afterward. The loss on ignition included organic matter and water from the hydrated minerals such as chlorite and kaolin. Since these minerals are present in relatively small amounts, the weight of water driven off by burning would be small—at most, a small per cent of the total weight. The average weight of dust per square foot was 47.8 milligrams. As would be expected, the various samples vary in weight, but it is remarkable that they are as close as they are. Weights of the individual samples are shown below:

Specimen No.	Total weight of dust per sq. ft.	Loss on ignition (mostly organic matter)	Weight of inorganic matter
1	39.7 mg.	7.1 mg.	32.6 mg.
2	40.7	13.9	26.8
3	52.8	13.1	39.7
4	57.8	17.1	40.7

Any calculation of the average amount of dust that fell per square mile would be inaccurate and of little importance except perhaps to show how wind is a factor that must be considered in the transportation of material from one place to another. This particular storm was the only storm that has been recorded in Hanover, New Hampshire, as causing the position of appreciable amounts of dust. Undoubtedly this lack of record is due to the small chance of noticing such

a dustfall except under the most favorable conditions. For those who are interested in estimates of the total quantity of dust carried by this storm we present the conservative estimate of 150,000 tons. A decrease in the amount of material was noted from west to east. At Ottawa, Ontario, 2.88 tons per square mile fell; at Montreal, 2 tons per square mile; and at Hanover, New Hampshire, about 1.5 tons per square mile. These figures show how impossible it would be to estimate the total quantity with any degree of accuracy.

MICROSCOPIC CHARACTER OF THE DUST.

A microscopic examination was made of dust collected from five different localities: Colebrook, Groveton, Hanover, and Laconia, New Hampshire, and Newport, Vermont. Although varying slightly as to the relative percentages of the constituents, the samples contain the following: quartz, feldspar, kaolin, sericite, chlorite, biotite, hornblende, pyroxene, zircon, soot, lint fibers, iron oxides, spores, plant fragments, and diatoms. An estimate of the relative percentages of the different constituents in the dust is listed below:

Quartz and feldspar	60-80%
Soot, lint fibers, etc.	0-15%
Diatoms, spores, plant fragments	2-10%
All other constituents	5-10%

The quartz occurs both as rounded and as angular grains which are clear and glassy. In some cases the rounded grains are pitted and stained with iron oxides. The feldspar consists principally of orthoclase and untwinned plagioclase, but a few grains of microcline were observed. Most of the grains are angular, but some are well rounded. As a rule the feldspars are clear and glassy like the quartz and show no alteration whatever. Kaolin occurs in large opaque masses but was not found associated with the feldspars to any extent. Chlorite, sericite, biotite, hornblende, green pyroxene, and zircon are present in small amounts. Most of the specimens contain a considerable amount of soot and other materials having a purely local origin. A number of fragments of volcanic glass were found in the sample from Hanover, but none of this material was observed in any of the other four specimens. Volcanic glass was also reported from Toronto by D. R. Derry of the University of Toronto.

Dr. W. J. Fisher of the Harvard Observatory found a number of blue-green algae in the dust from Colebrook.

Mr. A. L. Washburn of Dartmouth College examined some of the dust and found the following organic material:

11 different species of pollen grains (including Abies, Betulaceae, Pinus, and Tsuga)
3 different species of fungus spores (including Alternaria)
1 fern spore
1 fragment of starfish

The dust from Newport, Vermont, is notably reddish-brown due to an abundance of iron-oxide stain on the quartz and feldspar. Part of this sample was treated with concentrated hydrochloric acid and the color was removed completely, the quartz and feldspars becoming clear and colorless. The stain was apparently due to the presence of iron oxide. The Groveton sample was also reddish-brown but to a lesser degree. The other three samples were black as a result of the presence of organic matter and soot. Brown snow was reported in other parts of New Hampshire and Vermont and also in Montreal, whereas pink snow fell in the Laurentians.

One of the most interesting features of the dust is the presence in all samples of a considerable number of diatom tests. These are composed of hydrous silica and have various markings on their surfaces. Some are cigar-shaped with a length of about 30 microns and a width of from 5 to 10 microns. Another more abundant species attains a length of from 35 to 75 microns and varies from 10 to 20 microns in width. The Groveton dust was found to be particularly abundant in these skeletons and a small sample was sent to Washington for identification. Mr. K. E. Lohman of the United States Geological Survey kindly studied the material and found the following diatoms present:

Fragilaria sp.
Gomphonema parvulum (Kützing) Grunow var. micropus (Kützing) Cleve
Caloneis trinodis (Lewis) Meister
Navicula mutica Kützing
Navicula mutica Kützing var. cohnii (Hilse) Grunow
Stauroneis legumen Ehrenberg
Pinnularia borealis Ehrenberg
Pinnularia leptosoma Grunow
Epithemia sp.
Hantzschia amphioxys (Ehrenberg) Grunow

In regard to the source of these diatoms Mr. Lohman writes:

"All of these species are represented at present in ponds, lakes, and rivers scattered over a large part of the United States, and many of the species are common in Europe. Although all of them may be found living in those fresh water environments, *Navicular mutica* and var. *cohnii, Caloenis trinodis*, and *Hantzschia amphioxys* also inhabit brackish estuaries and slightly saline lakes. *Navicula mutica* has also been found living in the Arctic Sea and in the open sea off the West Indies. At first sight this might seem to indicate that this assemblage came from a brackish water estuary or lagoon, or from their desiccated edges, but in this case the addition of truly marine species would be expected and none was found. It is difficult to postulate a wind that would pick up only this assemblage from such a source without including some of the sea spray (with its contained diatoms) which would have been available near by. Thus, the most plausible indication offered by this assemblage as to the possible origin of the material is that the diatoms came from inland."

Measurements, with a micrometer ocular, of the size of the mineral particles of the dust show that they range from about 2 microns up to about 150 microns. The following list shows the percentages by volume of the various sizes in three of the samples:

	Vermont	New Hampshire	
Sizes in Microns	Newport Dust	Groveton Dust	Laconia Dust
Less than 10	60%	50%	25%
10- 25	20	20	50
25- 50	10	20	20
50-150 (approx.)	10	10	5

Since the dusts from Hanover, New Hampshire, and Colebrook, New Hampshire, are very similar in grain size to those of Newport, Vermont, and Groveton, New Hampshire, we may generalize and say that in most samples one-half of the material is less than 10 microns. The Laconia, New Hampshire, dust, on the other hand, is somewhat coarser, one-half of the grains ranging from 10 to 25 microns in diameter.

Dust from the storm of March 7-10, 1918, which fell over the Great Lakes region of the United States was described by

A. N. Winchell and E. R. Miller, who gave the following mechanical analysis:

Separates	Sizes in Microns	Per Cent
Clay	less than 5	11.145
Fine silt	5- 10	22.005
Medium silt	10- 25	56.169
Coarse silt	25- 50	5.988
Very fine sand	50- 100	1.215
Fine sand	100- 250	1.035
Medium sand	250- 500	0.580
Coarse sand	500-1000	0.290
Fine gravel	1000-2000	1.078

A comparison of this dust with the dust of the present discussion shows that the latter is on the whole finer, and that it contains a much larger percentage of material less than 10 microns. The Laconia dust, however, is remarkably similar in size to that described by Winchell and Miller. The highly sorted character of all of these dusts illustrates well the effectiveness of the wind as a sorting agent.

ORIGIN OF THE DUST.

Four possible theories as to the origin of the dust presented themselves when work was started on this problem. They were: local dust, volcanic dust, meteoric dust, and dust picked up in the semi-arid part of western United States. The presence of volcanic glass, diatoms, and minerals such as hornblende and pyroxene proved that this material was not of local origin. The abundance of diatoms and well-rounded and pitted grains of quartz and feldspar showed that the dust had not been thrown into the air by a volcanic eruption. Nothing was found in the dust to indicate that the material or any part of it had arrived on this planet from celestial bodies, so this possible origin was also dismissed. A theory that will explain the presence of volcanic material and well-rounded grains is necessary. A theory postulating that the volcanic material had been picked up along with the other material would account for the facts.

A study of the weather maps, and especially the winds, on the days preceding this storm gives the probable direction from which the dust came. This, coupled with the areas of snow cover and recent rainfall, would limit the area from which winds could have picked up fine material and carried it into the upper atmosphere. The accompanying map shows the

area in which there had been precipitation or snow cover during the time directly preceding the storm. It also shows the path of the storm center and its position at various times.

The memorandum furnished by Mr. Patterson of Toronto, Ontario, sums up the data on this storm rather well:

"An examination of the weather maps and especially the winds on the previous day indicates the probable direction from which the dust came. The synoptic map for 8:00 P. M., December 14, 1933, shows there had been strong southerly winds over Texas and the Gulf States with several destructive tornadoes reported in this region in the newspapers. The northern limit of the warm air was a line from Lincoln, Nebraska, east-southeast to Knoxville, Tennessee. In the synoptic maps for December 15, 8:00 A. M., just twelve hours later, the warm air at the earth's surface had advanced about 500 miles northeasterly to a line through London, Ontario, Cleveland, Ohio, and the midpoint of Lake Michigan. At heights of 5 to 20 thousand feet above the earth's surface, warm air extended considerably north of this line causing snow at many stations in Ontario and Quebec. This warm air current appears to have carried with it a large amount of dust which could easily have been carried up to great heights in the tornadoes reported from the southwestern United States."

The warmer air that was brought in along the storm center which traveled from Pueblo, Colorado, north-northeast to the James Bay region on December 14 and 15 undoubtedly contained the dust which was deposited with rain and hail. The precipitation was caused by the mixing of the warm upper layer and the cold lower layer; otherwise the raindrops would not have turned to hail as they fell through the lower layer of air. It is probable that only a small part of the dust was removed from the atmosphere at this time because of the lack of mixing in the warm and cool layers of air. It is in this band where mixing occurs that precipitation takes place. Definite proofs that the dust was picked up around northern New Mexico, Texas, Oklahoma, western Kansas and Nebraska, and eastern Colorado are lacking, but all evidence points to that region as the source of the dust,

DARTMOUTH COLLEGE,
HANOVER, N. H.,
AND
HARVARD UNIVERSITY,
CAMBRIDGE, MASS.

ARCHEAN RIPPLE MARK IN THE GRAND CANYON.

JOHN H. MAXSON* AND IAN CAMPBELL.*

In a recent paper Eskola[1] has assembled and discussed much evidence from Fennoscandian rocks bearing on the uniformitarian ("actualistic") interpretation of the Archean. He points out the desirability of obtaining fuller and more accurate details of the conditions existing in the earliest of the geological eras.

It seems worth while, therefore, to set on record the occurrence of a ripple-marked quartzite in the Archean of the Grand Canyon. The discovery of this significant sedimentary feature was made in the fall of 1933, while the writers were engaged in field studies, forming part of a program of research on the geology of the Grand Canyon, sponsored by the Carnegie Institution of Washington, through its president, Dr. John C. Merriam.

This particular bed occurs in a thick series of quartzites and quartz-mica schists, two-thirds of a mile west of the mouth of Monument Creek.** Reference to Figure 1 will indicate the relationships of this body of rocks to the overlying Paleozoic section of the Grand Canyon. The bed in which the ripple mark occurs is a granular mosaic of quartz grains, averaging one millimeter in diameter, which appears to have been originally a well-sorted quartz sand. As a result of metamorphism the quartz grains have been recrystallized and some feldspar, biotite and hornblende have been developed. The quartzite bed in question has a thickness of two feet, stands in vertical position and strikes about N. 35° E. The marking is exposed in a crevice about twenty feet above the low-water stage of the Colorado River. The crevice contains pebbles such as the river is now transporting, which indicates that the area is submerged during some floods.

The preservation of this ripple mark through the succeeding metamorphism and diastrophism may call for some comment. It seems that a fortunate combination of several factors may be responsible for its survival. Thus, in the Archean section

* Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California.

** See the Bright Angel sheet of the Topographic Atlas of the United States.

[1] Eskola, P., Conditions during the Earliest Geological Times, as indicated by the Archean Rocks, Ann. Acad. Sci. Fennicae, Series A, Vol. 36, No. 4, 1932.

under discussion, there has been much less granitic injection than occurs some six miles to the east at the foot of the Bright Angel and Kaibab trails, the region most commonly seen by visitors to the inner gorge. Metamorphism has been correspondingly less, and has consisted, as indicated above, largely of recrystallization. It is possible that a considerable part of this recrystallization had been accomplished before the major diastrophism, with the result that the sand grains of the ripple mark were thoroughly welded to, and had become an integral part of, the now massive and competent quartzite bed on which they occur. Finally, the ripple mark is overlain by relatively incompetent mica schist. This schist is believed to have been an argillaceous sediment and throughout its history more accommodating to stress and metamorphic agencies than its underlying bed. In the differential movements which almost certainly accompanied the diastrophism this structural feature of the quartzite, therefore, survived, although no doubt at the expense of some local crushing and destruction in the overlying schist.

The ripple mark, which is shown in Figure 2, is symmetrical, indicating formation by oscillatory motion of water. Ripple mark of this type is believed[2] to characterize the sandy bottoms of lakes and other quiet bodies of water. The wave length is very short, varying from one-half to three-fourths inch, while the amplitude varies from one-fourth to three-eighths inch. While ripples of long wave length may not form in shallow water, E. M. Kindle and W. H. Bucher[3] consider that short wave lengths offer no certain criterion of depth.

Supplementary evidence as to depth in this instance is afforded by a faintly rill-marked quartzite, which was found some fifteen feet stratigraphically below the ripple-marked quartzite. This strand-line feature plainly points to a shallow-water origin for this part of the section. It, therefore, appears probable that the ripple mark was also formed under similar conditions. This view accords well with the hypothesis previously advanced by the writers,[4] of accumulation of these Archean sediments, in a shallow, subsiding geosyncline.

[2] Kindle, E. M., Recent and Fossil Ripple Mark, Can. Geol. Sur., Mus. Bull. 25, p. 23, 1917.

[3] Twenhofel, W. H., A Treatise on Sedimentation, p. 663, 1932. Kindle and Bucher state that, "Small ripple marks may . . . . form in both shallow and deep waters, and their occurrences are, therefore, no indication of depth."

[4] Campbell and Maxson, Some Observations on the Archean Metamorphics of the Grand Canyon, Proc. Nat. Acad. Sci., Vol. **19**, No. 9, 806-809, 1933.

Fig. 1. A view looking west down the inner gorge of the Colorado River from the Tonto Platform north of Dana Butte. The arrow indicates the site of the Archean ripple mark. The canyon opening a short distance to the left is that of Monument Creek. Here the nearly horizontal Paleozoic system directly overlies the vertical Vishnu schist, the Algonkian Unkar and Chuar series being absent.

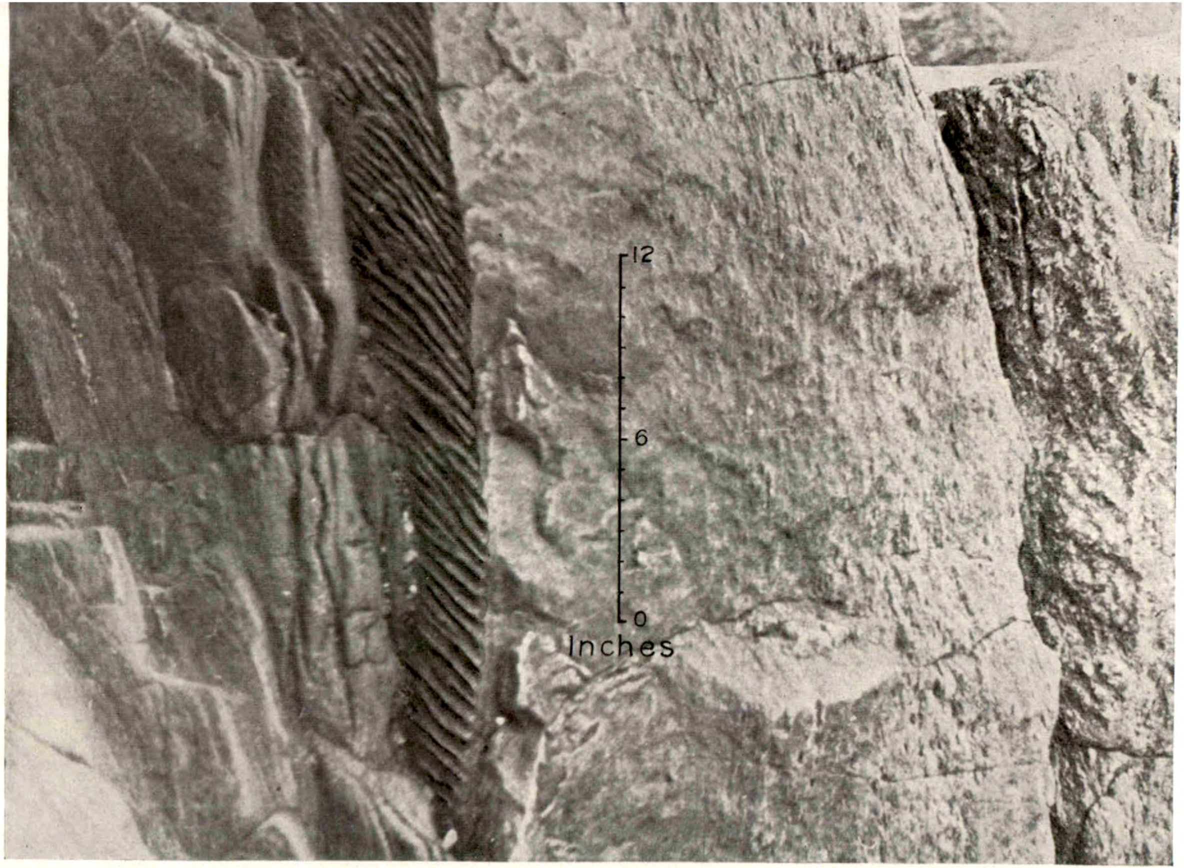


Fig. 2. Ripple mark in crevice between mica schist and massive quartzite bed. Note that the marking is on bedding plane at right angles to cross section of the bed exposed in the photograph. East is to the left. Archean in Grand Canyon, Arizona. 2/3

The crests of the ripples are sharp and, while occasionally anastomosing, show no evidence of interference. Troughs are definitely rounded and concave. The crests face eastward on the vertical bedding plane of the quartzite, showing that beds in that direction are younger. This evidence agrees with that provided by cross-bedding, preserved in other quartzites, near Monument Creek, a mile and a half to the west near Hermit Creek, and about four miles to the west on Boucher Creek. These data are proving extremely valuable in ascertaining the structure of the Archean section. It appears that at least twenty-five thousand feet and perhaps several times this thickness of Archean strata are exposed across the strike in the western part of the Bright Angel quadrangle. The section embraces several types of sediments and possibly some volcanic rocks which thus may ultimately be subdivided into several formations, representing distinct epochs of Archean time. The continuous exposure should make it possible to establish a chronologic sequence for this least-known era of geologic time.

Aside from the value of ripple mark in geologic investigation, in a structurally complex region, this example from the Grand Canyon is interesting because of its antiquity. According to the present knowledge of the writers, it is the oldest ripple mark to be described from North America and as old as any yet seen elsewhere in the world. A number of Algonkian occurrences have been recorded in North America. Excellent examples in the Unkar series of the Grand Canyon were known to the early explorers. The extensive marking of beds in the Belt terrane was noted by Ransome and Calkins.[5] Hore[6] has described symmetrical ripple mark from the Huronian of Ontario. But the only previously reported Archean ripple mark is from Europe. In describing certain leptites of southwestern Finland, Sederholm[7] makes the following comment: "Still this occurrence (cross-bedding) is in no way a unique phenomenon. In Dalsland on the western shore of Wernern lake in Sweden I have not only seen cross-bedding with just as much clarity in a vertically standing glassy quartzite, but also clearly preserved ripple mark. Both

[5] Ransome and Calkins, The Geology and Ore Deposits of the Coeur d'Alene District, Idaho, U. S. G. S. Prof. Pap., 62, p. 30 et al., 1908.

[6] Hore, R. E., Ripple-marked Huronian Quartzite, at Nipissing Mine, Cobalt, Ontario, Mich. Acad. Sci. Rept., Vol. **15**, p. 59, 1913.

[7] Sederholm, J. J., Uber eine Archäische Sedimentformation im Südwestlichen Finland, Bull. Comm. Geol. Finlande, No. 6, p. 98, 1899.

were described in 1870 by A. E. Törnebohn (Beskrifing till kartbladed No. 34 Åmål. sid. 15) and according to him there is not the slightest doubt that the so-called Eurite-quartzite formation in which this quartzite occurs belongs to the ancient Archean complex of Sweden and is older than some gneissic granites of the region. Even in the quartzite from Tiirismaa near Lahtis in southern Finland, which has been much more thoroughly metamorphosed and which is probably older than these, one finds on vertical bedding planes furrows which *possibly* are to be considered as ripple mark." (Translation.) Although Sederholm[8] now considers the Dalsland formation as somewhat younger than the Jatulian portion of the Proterozoic, the Tiirismaa quartzite occurs in the Leptite formation and is regarded as belonging to the Svionian or older portion of the Archean.

The ripple mark from the Grand Canyon here described is of interest not only because of its antiquity and its significance with regard to structure, but also because it is indicative of the part played by the ordinary agencies of sedimentation in the first recorded history of the earth.

[8] Sederholm, J. J., On the Geology of Fennoscandia, with Special Reference to the pre-Cambrian. Explanatory Notes to Accompany a General Geologic Map of Fennoscandia. Bull. Comm. Geol. Finlande, No. 98, p. 20, 1932.

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CLIMAXES OF THE LAST GLACIATION IN NORTH AMERICA.

ERNST ANTEVS.

ORDER OF CULMINATIONS OF THE ICE LOBES.

The southward lobes of the last North American ice sheet reached their greatest extent at different times. The moraine that marks the periphery in eastern and central Long Island, is, in the western part of the island, over-ridden by a somewhat younger moraine, which here, in New Jersey, and in Pennsylvania, forms the limit of the last glaciation. The terminal moraines in Ohio, Indiana, and Illinois may have been deposited somewhat later by the Great Lakes lobe of the Labrador ice. The terminal moraine in south-central Wisconsin was then formed by ice also deriving from the Labrador center.[1] The peripheral young red drift in northern Wisconsin was laid down still later by ice from the Patricia center south of Hudson Bay. The outermost moraines of the youngest drift in Minnesota, Iowa, and the Dakotas, finally, were formed at a yet more recent date by the Des Moines-Dakota ice lobes from the Keewatin center.[2] Each ice lobe retreated shortly after its climax and halted or readvanced during succeeding culminations of other ice lobes. The average time interval between the climaxes seems to have been roughly 2000 years.

At the culmination of the Patricia ice in northern Wisconsin, the eastward limit of the ice sheet seems to have been at the Port Huron morainic system, which encircles the southern edges of the Huron and Ontario basins,[3] at the Finger Lakes and the Catskill moraines, at Northampton.[4] During the climax of the Dakota-Des Moines lobes, the ice border in the Great Lakes region stood somewhat north of the Port Huron morainic system,[5] and in New England perhaps at Claremont-Lake Winnepesaukee.[6] This climax seems to have occurred about 25,000 years ago, while the culmination of the New England-New York ice lobe in Long Island may have taken place roughly 35,000 years ago.

The terminal moraine on the west side of the Dakota lobe (the Altamont moraine) continues from the northwestern corner of North Dakota northwestward into Canada and lies well east of Edmonton.[7, 8] North of Edmonton its trend is

not known, but the Keewatin ice border during this culmination probably joined the Cordilleran ice near the foot of the Rockies at about Lat. 55° N., for then the ice axis seems to have lain over Great Slave Lake (see below). In the broad wedge between the Altamont moraine and the Rockies there is on both sides of the International Boundary a drift which, though distinctly older than the Altamont moraine, is neither greatly eroded nor deeply weathered, and which is referred to the early Wisconsin by Alden[9] and partly to the early Wisconsin by Johnston,[10] whereas it is largely or wholly regarded as pre-Wisconsin by Sardeson[11] and Johnston and Wickenden.[12, 13] This drift may have been deposited during early expansion of the Keewatin ice of the last glaciation; it appears to include the drift of Iowa and adjacent states designated as the Iowan. The Iowan drift is shown by Kay[14] to be closely connected with the Wisconsin, it being leached to a depth of about 5½ feet, whereas the drift of the Des Moines lobe is leached to a depth of about 2½ feet. And it is proved by Leighton[15] and his associates to be so little older than the Wisconsin drift that it is to be regarded as an old member of the deposits of the last glaciation. Thus the Iowan drift was overlain by the Peorian loess before it was leached; and in Illinois the Peorian loess was covered by the Wisconsin till, even before the loess was weathered. The Iowan till, where forming the surface, is leached to somewhat less depth than is the Peorian loess outside the Iowan drift border. On the other hand, the Peorian loess rests in places on the late Sangamon loess which has a soil and a youthful profile of weathering, and the Sangamon loess rests in turn on the Illinoian till, which has a mature profile of weathering, showing that the Peorian loess and also the Iowan drift are widely separated in age from the Illinoian drift.

To sum up, ice from the Keewatin center may have spread southward to the foot of the Rockies in northern Montana and southeastward to eastern Iowa (Iowan drift) during early stages of the last glaciation. The climax in Montana was probably somewhat earlier than that in Iowa. The Labrador ice culminated much later in New England. Thereupon followed a rather rapid succession of climaxes of different ice lobes, ending with the Des Moines-Dakota lobes which represent a rejuvenation of the Keewatin ice.

PROBABLE MODE OF DEVELOPMENT OF THE ICE SHEETS.

The stated order of development of the main centers of the last glaciation was suggested by Fredrik Enquist in 1916 as being a requisite for the formation of the several ice sheets, because of the physiographic and climatic conditions of the regions of ice accumulation. Enquist's[16] view, augmented by the writer, is briefly as follows: With the sinking of temperature and increase of snowfall, ice accumulated in the Coast Ranges, the Interior Plateau, and the Rocky Mountains of British Columbia, Yukon, and the panhandle of Alaska. Gradually the glaciers coalesced and filled the mountain valleys and the plateaus, forming a sheet through which only the highest mountain ridges and summits protruded. In the south, where the Rockies comprise a broad belt of ridges, 8000 to 12,000 feet high and nearly 500 miles from the Pacific Ocean, and rise abruptly from the Great Plains,[17] ice spread only well beyond the foothills.[18] In the zone between the 54th parallel of latitude and Mt. Logan, in which only isolated summits reach above 8000 feet, the glaciers did flow down the eastern slopes of the Rockies and spread onto the plains, and the winds carried much moisture across the mountains. These mountains, which are now effective precipitation barriers (the rainfall inside them is 10 to 20 inches), may then have been lower by some 2000 or more feet, having been pressed down by the weight of the accumulating ice. The Coast Ranges and the westerly winds blowing the snow landward across the mountains may have prevented excessive wastage of ice to the Pacific and may have favored flow and expansion of the ice eastward over the plains. Again, north and northwest of Mt. Logan, the Alaska Range was sufficiently high to intercept rather effectively the moisture from the Pacific, so that the Pleistocene glaciation on this range, like the modern glaciation, was essentially limited to the Pacific slopes, the lee side having but comparatively short glaciers.[19]

When the ice on the plains east of the precipitation corridor between the 54th parallel and Mt. Logan had reached the same level as the ice field of the mountains, it developed an independent center or axis of outflow—*the Keewatin center.* This ice center shifted its position, as the ice sheet changed in extent, thickness, and shape. During the greatest extent of the ice in early Wisconsin time the central axis, as judged from old north-northwest striae on Coronation Gulf,[20] may

have lain on a line running just east of Great Slave and Athabasca lakes, over land mostly 1000 to 1500 feet high. The conditions in western Canada were then fundamentally the same as in Europe during the glaciation, where, owing to low temperature and moist westerly winds, an ice sheet originated in the Scandinavian Mountains, formed a divide east of the highest ranges, and spread eastward and southward. During the culmination of the Keewatin ice in late Wisconsin time, the central axis perhaps passed through Great Slave Lake toward which young, northerly striae on Coronation Gulf[20] and striae on the Mackenzie between Great Slave and Great Bear lakes converge. During the subsequent dissipation of the ice an ice-free belt may soon have formed on the lower Mackenzie River and along the base of the Rocky Mountains.[21] As Johnston also points out, this uncovered belt may have been the oldest possible route of immigration of the Indian to southern Canada and the United States. If the late culmination of the Keewatin ice took place about 25,000 years ago and the drainage of Lake Agassiz roughly 13,000 years ago, this route on the western edge of the Great Plains may have been open for some 20,000 years. When it was first used is another problem. The last stand of the Keewatin ice sheet seems to have been half-way between Great Slave Lake and Hudson Bay.

At present the long and extremely severe winters in Labrador have for the most part very clear weather. Because of the low over the North Atlantic the winds, in winter, are almost constantly from the west or northwest. Coming from snow-covered and ice-bound land and bays, the winds are relatively dry and icy cold. Since they undergo little further cooling on their way across the hilly plateaus, they precipitate little snow; but the bulk of the snow, which is very small, considering the length of the winter and the fact that the temperature for five months hardly ever rises above freezing, is derived occasionally from north and northeast winds.[22] As a consequence there are now only small glaciers (in the cirques and scattered snow fields about the mountain tops and in ravines away from the sun),[23] while on the north coast only July, August, and September are without snow, and mountain summits reach over 4000 feet in altitude.[24]

Evidently, the development and maintenance of a Pleistocene ice sheet in Labrador required a much greater snowfall than occurs at present. Evidently, also, any large quantity of

winter precipitation in the peninsula must derive its moisture from open water: from the Atlantic. This postulates east or northeast winds in winter, which in turn require a high pressure over the North Atlantic where there is now a permanent low. Southward displacement of the Icelandic low could only occur through the development, at high latitudes, of such strong high-pressure areas as must have existed over the Pleistocene ice sheets, and through the lowering of the temperature of the water of the North Atlantic and the Norwegian Sea.[25] Therefore, extensive glaciation may not have started in Labrador until large ice sheets with anti-cyclones had formed in Keewatin, Greenland, and North Europe. The Labrador ice sheet, with its main center at the intersection of Long. 70° and Lat. 55° (A. P. Low), where the mean elevations are 1000 to 2000 feet, and expanding largely southward and southwestward, was a true image of the European ice sheet on the other side of the Atlantic.

The agreement of recent datings and correlations of the several ice lobes with this plausible explanation of formation is noteworthy.

AGE OF THE LAST PLUVIAL EPOCH IN THE GREAT BASIN.

The early culmination of the last Keewatin ice sheet and its late rejuvenation makes it pertinent to consider the ages of extensive glaciations in the mountains of the Southwest and of the last Pluvial epoch of the Great Basin. The age of the last Pluvial is of special importance for the discussion of the time of immigration of the Indian to this continent. The old glaciers on the eastern slope of the Rocky Mountains of Montana which, because of their proximity to the Keewatin ice, could be expected to give useful information, are not sufficiently well dated.[26] However, the moraines of the youngest extensive glaciation on the eastern slopes of the Sierra Nevada, the Tioga stage, are almost unaltered, and the related striae are generally preserved even on granite, suggesting that this glaciation was a correlative of the late Wisconsin of the North.[27] The next older extensive glaciation of the region, the Tahoe glaciation, which is rather closely related in age to the Tioga, is correlated by Blackwelder[28] with the Iowan of the Middle West.

The last greater Mono Lake was probably contemporaneous

with the Tioga glaciation, for in Leevining and Lundy canyons it carved marked terraces on the ends of the lateral ridges of the Tahoe moraines, after the terminal parts of the moraines had been largely eroded away by the brooks.[29] The Tioga moraines are merely notched by the brooks.[30] In Little Cottonwood canyon, Utah, the eroded moraines of the Tahoe age are partly covered by delta deposits from the Bonneville stage, which may be of Tioga age.[31] All the shore lines of Lake Lahontan in Nevada seem to date from the last high stand of the lake. The freshness of all the features of the last Pluvial lakes is additional indication that they are correlatives of the relatively short valley glaciers of the Tioga age and of the late Des Moines-Dakota lobes of the Keewatin ice, not of the longer Tahoe glaciers and the maximum extent of the Keewatin ice in early Wisconsin time. This is in harmony with the view that the age of heavy rainfall in the semi-arid belt, the Pluvial epoch, coincided with the greatest southward displacement of the North Atlantic and the North Pacific lows, and was connected with the decrease in precipitation over the ice sheets, which together with rise in temperature caused the deglaciation.[32]* The Sierra Nevada was probably about as effective a precipitation barrier then as at present, for its last great uplift took place in early Pleistocene time,[34] and its Pleistocene glaciers, forming a belt 25 to 30 miles wide, may not have appreciably weighted down the mountains.

As the ice sheets and their anti-cyclones gradually waned, the North Atlantic and the North Pacific lows migrated northward to their modern sites, and the existing climatic conditions were ushered in. The last Pluvial epoch of the Great Basin may thus have been contemporaneous with the climax of the Des Moines-Dakota ice lobes and with the subsequent stages of the ice retreat. It probably prevailed from some 25,000 to some 15,000 or 10,000 years ago.

SUMMARY.

The principal statements and conclusions made are summed up in the following table, which reads in chronological order from the bottom.

* The primary cause of the deglaciation was perhaps a temperature rise, for low temperature near the ice surface may have been the most essential condition of precipitation in the glacial anticyclone.[33]

Climaxes of the last glaciation in North America.

Ice center	In states	Moraines	Substages	In Sierra Nevada	In Great Basin
Cordilleran				Tioga	Last Pluvial
Keewatin	Minnesota, Iowa, the Dakotas	Bemis, Altamont (Des Moines-Dakota lobes)	Mankato		
Patrician	Wisconsin	St. Croix	Unnamed (Late Wisconsin) (Two Creeks forest bed)		
Labrador	Wisconsin	Johnstown	Cary (Middle Wisconsin)		
	Ohio, Indiana, Illinois	Shelbyville, Bloomington	Tazewell (Early Wisconsin)		
	New York, New Jersey, Pennsylvania	Harbor Hill, Morristown	New Jersey		
	Massachusetts, New York	Ronkonkoma	Long Island		
			(Peorian loess)		
Keewatin	Iowa, etc.		Iowan		
	Montana		Montana		Pluvial?
Cordilleran				Tahoe	

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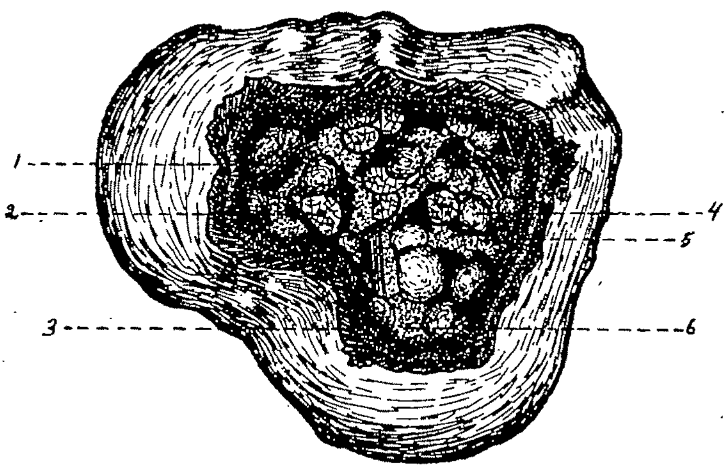
Auburn, Maine.

THE EXCAVATION OF A METEORITE CRATER NEAR HAVILAND, KANSAS.

H. H. NININGER AND J. D. FIGGINS.

In the Proceedings of the Colorado Museum of Natural History (vol. xii, No. 3) a most interesting account (illustrated) is presented of the discovery and excavation of a small meteorite crater recently discovered near Haviland, Kiowa County, Kansas. This little crater is located on the farm



where so many of the "Brenham" or Kiowa County meteorites were gathered between 1885 and 1900. Although the farm was visited by several eminent geologists in the '90s, the small "buffalo wallow" in the midst of the meteorite-sprinkled area seems to have attracted no attention whatever until 1925 when H. H. Nininger visited the farm in the hope of discovering an overlooked specimen of the famous Brenham fall.

The form of the little depression attracted Nininger's attention even though thirty years of wheat farming had almost obliterated its elevated rim, and after several years of negotiating he was finally permitted, in June, 1933, to excavate it in collaboration with the Colorado Museum of Natural History.

The excavation revealed a layer in the form of an inverted oblique cone, heavily impregnated with meteorite fragments—often as many as 50 to 100 per cubic foot. The fragments

ranged in size from less than a gram to 40 kgs. each. The largest found were at the apex of the cone, 11 feet underground.

The Brenham meteorite shower was classified as a pallasite more than forty years ago and the crater specimens evidence clearly their identity as a part of that fall; but nearly all of them have been completely altered so that the metallic constituents are changed to oxides. Some have undergone the change without noticeable rearrangement of their internal structure, but in many of the specimens a very striking metamorphosis has taken place by which the oxidation products have migrated to form a ferrite shell or outer wall within which are nested the olivine spheroids. This type is termed meteorodes by Professor Nininger. In some cases the olivines were found to have broken down to form olivine sand within the ferrite shell and not a few were found in which alteration had gone so far that the center appeared to be merely iron-stained soil.

Two explanations are offered to account for the formation of the crater as found, and free discussion of the problems presented by this discovery is invited by the authors.

DENVER, COLORADO.

SCIENTIFIC INTELLIGENCE.

Geology.

The Cambrian of the Upper Mississippi Valley, Part III, Graptolitoidea; by RUDOLF RUEDEMANN. Bull. Public Mus. Milwaukee, Vol. 12, pp. 307-348, pls. 46-55, figs. 1-4, 1933.—Heretofore we knew of but a single named graptolite from the American Upper Cambrian (*Dendrograptus hallianus*). Now fifteen additional forms are described, of which thirteen are new species or varieties in the genera *Dendrograptus, Callograptus, Acanthograptus, Dictyonema,* and *Haplograptus* (new). The *Dictyonema schucherti* from Vermont is now known to be from the Upper Cambrian, and not from the Lower, as the author was informed. *D. kindlei* of Gaspé, Canada, is not from the Middle Cambrian, as stated on page 313, but from the Upper Cambrian, as given on page 319. Accordingly, no graptolites are known back of the Upper Cambrian. We congratulate the author on the many new additions to these hydroids or are they bryozoans? C. S.

The Bison of the Western Area of the Mississippi Basin; by J. D. FIGGINS. Proc. Colorado Mus. Nat. Hist., Vol. 12, No. 4, pp. 16-33, pls. 1-9, 1933.—The author revises the Pleistocene bisons of the High Plains, and defines seven species and subspecies, of which six are new. This revision will eventually become of considerable value in the chronology of the Pleistocene formations of the High Plains and elsewhere. C. S.

Papers concerning the Palaeontology of California, Arizona, and Idaho. Contributions to Palaeontology, Carnegie Institution of Washington, Pub. No. 440, pp. 135, 28 pls., 11 figs., 1934.—Included in this publication are the following papers: I, Tertiary mammals from the auriferous gravels near Columbia, Calif., by J. C. Merriam and Chester Stock, with (II) Notes on the geologic section, by G. D. Louderback; III, Perissodactyla and IV, Carnivora from the Sespé of the Las Posas Hills, Calif., by Chester Stock; V, Anchitherine horses from the Merychippus zone of the North Coalinga district, Calif., by F. D. Bode; VI, Pleistocene mammalian fauna from the Carpinteria asphalt, and VIII, A rodent fauna from later Cenozoic beds of southwestern Idaho, by R. W. Wilson. The titles of these papers relating to Cenozoic mammals are sufficient indication of their content.

Paper No. VII; *The Coconino sandstone—its History and Origin*, by E. D. MCKEE.—This is the best account so far published regarding the physical make-up of this perplexing formation in the Grand Canyon area. The only fossils present are reptilian and amphibian footprints. The Coconino sands, the author holds, were brought by winds from the south and deposited in the main as dunes, and locally in shallow fresh waters, not brought by rivers

from the northeast, as held by other stratigraphers. During this deposition the climate became more and more arid. Finally, the Kaibab sea of Middle Permian time spread from the northwest across these wind-blown sands. C. S.

Die in Organischer Substanz erhaltenen Mikrofossilien des Baltischen Kreidefeuersteins; by OTTO WETZEL. Palaeontographica, Bd. LXXVII and LXXVIII, Abt. A, pp. 141-186, 1-110, 7 pls., 15 text figs., 1933.—This paleontologic memoir is of the greatest interest, since it reveals a world of marine micro-organisms seldom seen by paleontologists. Flintstones, of original but diagenetic origin, are known in many formations from the Cenozoic to the Cambrian, and there is every reason to believe that such are common also in Proterozoic strata. This memoir also suggests a fertile field of work for microscopists, and raises the hope that astonishing discoveries are yet to be made in the flints and limestones, especially those of the Precambrian. Anyone who has flintstones of *primary* origin (not of secondary origin, through leaching and deposition by ground waters) from any pre-Mesozoic formation, should communicate with Doctor Wetzel, at Eutin, Germany, since he wishes to continue his work.

The paper contains a description of the author's method of preparation, which is largely by spalling, over 15,000 flakes having been examined, and of his study of the material microscopically, photographically, chemically, and physically. The heliotype plates reproduce his untouched photographs and reveal a wonderland of organisms, chiefly of Flagellata (Peridinians, transition forms? to Radiolarians, etc.), Radiolaria (rare), and spinose and smooth egglike bodies (Hystrichosphaeridae). Some of the latter also suggest flagellates, and the author says they surely are not desmids or eggs of copepods, as has been supposed. Also present are "brush teeth" which suggest conodonts, but because of their small size are called "micro-conodonts," and still other organisms. C. S.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Complete Edition of Darwin's "Voyage of the Beagle."—"The voyage of the Beagle," wrote Charles Darwin, "has been by far the most important event in my life, and has determined my whole career"; which might otherwise have been that of a clergyman. Such had previously been his almost fixed purpose; even after five months at sea he wrote home: "I find I steadily have a distant prospect of a very quiet parsonage." In the earlier editions of his Diary* about a third of the original manuscript was replaced by a somewhat larger measure of scientific descriptions, drawn from records which had been kept in separate books, a total of over 2000 pages. The present edition presents for the first time the

* First edition: First and second issues, 1839; third issue, 1840; later editions, 1845, 1860, 1870.

original diary in full and verbatim. Even occasional misspellings are given, as written up during the voyage from 18 small notebooks. These were carried in the field along with the volume of Milton's poems that always accompanied the young man when he left the ship for land journeys.

The chief differences between the earlier and the new editions are summarized on pp. 441-442 of the present volume. By far the most interesting of them concern the account of "several long walks in the country" on the coast of Chile, August 5th, 1834. There, after brief mention of the occurrence of recent shells up to an altitude of 1300 feet, and the statement: "there are very few quadrupeds, and birds are not very plentiful," follow these lines (omitted from the earlier editions): "It seems not a very improbable conjecture that the want of animals may be owing to none having been created since this country was raised from the sea."

Four lines omitted from a short record of August 17th, 1836, near the end of the five-year voyage, reveal the hardships still suffered by the young naturalist. They are as follows: "We lie close hauled to the wind, and therefore there is considerable pitching motion; I suffer very much from sea-sickness. But it is on the road to England; in truth some such comfort is necessary to support the tedious misery of loss of time, health and comfort." The appearance of the new edition (Cambridge University Press, London, 1933) as a Centenary celebration of the famous voyage is most apposite and gratifying. W. M. DAVIS.

Recent Study of the South Wales Coal Field; by EMILY DIX.—I. Succession of Fossil Plants in the Millstone Grit and the lower Portion of the South Wales Coal Field (near Swansea), and a comparison with that of other areas. Paleontographica, v. 78, Abth.B., pp. 158-202, 13 figs. in text, Pls. 20, 21 (Stuttgart, 1933).

II. Sequence of Floras in the Upper Carboniferous with special reference to South Wales. Trans. Roy. Soc. Edinburgh, vol. LVII, Part III (No. 33), 1932-1933, pp. 789-838, 4 Text-figures.

These contributions follow the work of Professor Bertrand on the *Zones Vegetales du Terrain Houiller du Nord de la France*, appearing in 1914. Since then Dr. Dix has studied the South Wales field assiduously. She now comes to her subject as a worker able in the field, and a clear writer. Her results, living at the edge of the coal field, and based on personal observation and collection throughout, are particularly valuable.

The text figures of part two are in the form of compact double-page charts. While attention is given all factors, it is found that in using the plants as indicators for zones sufficiently thin to be of real value in correlation attention must be firstly directed to the species with short ranges. Such are rare, except at a few horizons; and since actual distribution must be incompletely known, the precise boundaries of certain of the zones cannot be definitely fixed.

Nevertheless, the South Wales coal fields are brought into far-reaching comparison. The Upper Carboniferous sequence is not only the most complete in Great Britain, but surely may now be held the best known. There are identified the broader zones similar to those assigned by Bertrand for the North of France, as well as the floral divisions of Jongmans for Holland, of Renier for Belgium, of Gothan for Westphalia, and as again seen in the Donetz coal-field by Zalessky. G. R. W.

Our Primitive Contemporaries; by GEORGE PETER MURDOCH. Pp. xxii, 614; 117 figs. and frontispiece. New York, 1934 (The Macmillan Co., $3.60).—A difficulty which all those giving instruction in anthropology have to meet is the lack of satisfactory student reading in the field of ethnography. In the majority of cases the available material on any given people is either too superficial or too brief, or else is too elaborately monographic or too widely scattered through a variety of sources, often in foreign languages. There has been thus a real need for an ethnographic handbook, giving within reasonable compass, clear, concise and up-to-date sketches of the culture of a selected series of tribes from various parts of the world.

This need has been met and on the whole most satisfactorily by Professor Murdoch's volume. It contains sketches of eighteen different peoples, ranging in culture from the Tasmanians to the Incas, and scattered through all the continents and Oceania. Each sketch is from thirty to forty pages in length, and gives first a brief outline of the environment of the group, then describes the various aspects of the culture, concluding with a selected bibliography. The sketches are purely factual and descriptive, and there is no theorizing, comparison or discussion of historical development or relationships. The aim is to give a clear and vivid picture of life as lived by a variety of what we call, for lack of a better term, primitive peoples.

The author's selection of the peoples to be described is in general happy, but seems open to debate in some cases. Thus the Samoans are hardly a fair example of the Polynesians, since their culture on its social and religious sides is so aberrant from the general Polynesian forms. The Polar Eskimos again, because of their isolation, had lost or modified several features of Eskimo culture, and are thus not as fully typical as some other groups would have been. Finally, the selection of the Kazaks, as one of the Asiatic peoples seems ill advised, since their native culture has been so largely erased by their conversion to Islam. The quality and accuracy of the sketches are quite uniformly high, yet here and there a minor slip has been made. Thus in the case of the Iroquois, their pipes are said to have been the finest north of Mexico, whereas the carved stone pipes of the Hopewell culture from Ohio must be admitted to be superior. Wampum, described

as freely used for ornament and treaty belts, was actually used hardly at all prior to European contact. Furthermore, the White Dog sacrifice is not referred to by any writer until the latter part of the eighteenth century, and it is doubtful whether this was an original pre-European element in the ritual. In the sketch of the Inca, a geographical slip has been made in describing the course of the Mantaro river as northward, since actually it flows throughout most of its course due south. The description of the Inca culture, particularly on its social and political sides, is extremely well done, but more attention might well have been called to the rather wide diversity of local cultures which still survived the crushing standardization that the Inca rule everywhere endeavored to impose.

Professor Murdoch's volume should be a boon not only to those giving instruction in Ethnography, but also to the general reader who wishes to find authentic and concise information as to the kind of life lived by "our primitive contemporaries." To both, it can be recommended as an ably prepared and interestingly written volume. R. B. DIXON.

Embryology and Genetics; by THOMAS HUNT MORGAN. Pp. vii, 258; 129 figs. New York, 1934 (Columbia University Press, $3.00).—For his outstanding contributions both in the field of developmental mechanics and in the study of the laws of heredity the author has merited the Nobel prize for 1933. In this new book he has summarized the recent progress in these two aspects of biology and has made a comprehensive survey of their interrelations, showing that the actions of the genes in controlling each of the many successive stages in the development of the individual are equally applicable to all the associated biological phenomena. The processes of fertilization, differentiation, regeneration, and sex determination are seen as responses to the hereditary endowment of the two germ cells from which the individual is derived. The potencies of each part of the embryo, as determined by recent experimental studies on localization and induction, are given particular attention.

The book is addressed to "students in colleges and medical schools that do not get in their course in embryology the broader philosophical outlook"; they, as well as other readers, will find in it the clearest and most comprehensive discussion that has yet appeared concerning the potencies which underlie the developmental processes of the individual. The numerous illustrations and diagrams are of extraordinary merit and the references to literature, wisely placed at the end of the book, are well chosen. W. R. C.

Insects as Material for Study; by G. D. HALE CARPENTER. Pp. 38; 1 plate. Oxford, 1934 (Clarendon Press, $1.00).—These two inaugural lectures present a lucid and well-reasoned discussion

of the adaptations and instinctive behavior of insects with particular reference to the bearing of the evidence which the study of insects furnishes in support of the theories of natural selection and evolution. W. R. C.

The Scientific Journal of the Royal College of Science. Vol. IV. Pp. 171. London, 1934 (Edward Arnold and Co., 41-43 Maddox St. W.I. Price 7s. 6d.).—This volume contains the series of papers read during the 1933-34 sessions before the following Societies: I. Imperial College Chemical Society (7 papers, pp. 5-70). II. Royal College of Science, Natural History Society (6 papers, pp. 75-129). III. Royal College of Science, Mathematical and Physical Society (6 papers, pp. 131-171).—A wide range of subjects is included in this volume, but it is not too much to say that all are interesting and valuable. The titles of some of the prominent papers will show their wide scope.

Group I includes: Gold, by D. McDonald: the occurrence, refining, etc. Aluminum, by R. Seligman: its protective film and inner structure. 3. Vitamin D and its properties, by R. K. Callow.

Group II. Taxonomic Botany and Researches on British Plants, by W. B. Turrill. Romance of Grassland, by W. Davies. Natural Selection: a defence of Teleology, by A. F. Baker. Fruit tree root system, by W. S. Rogers.

Group III. Molecular spectrum of N H, by R. W. B. Pearse. Noise, its measurement and abatement, by G. W. C. Raye. The Positive Electron, by P. M. S. Blackwell.

The Clay Resources of Indiana; by GEORGE I. WHITLATCH. Division of Geology. W. N. Logan, State Geologist. Indianapolis, 1933. Publication No. 123. Pp. 298; 40 figs., 9 tables.—Indiana ranks seventh among the ten states in this country which are prominent in the high value of their clay products. This is an important industry, developed within recent years. The present volume presents the subject with all desirable fullness. It opens with a discussion of the physical and chemical properties of clay. Then follows the technology of the industry from the procurement of the clay to the wares developed. Other chapters discuss the geologic and geographic distribution of the clays, and of the clay plants. Chapter seven gives in detail an account of the clay plants and their clays in the forty-four counties of the State.

Egyptian Government: Ministry of Public Works. Annual Report for 1927-1928. Part II. M. OSMAN, Under-Secretary of State. Pp. xiv, 283, with many charts. Cairo, 1933 (price P.T. 20).—In this volume the subject of irrigation, ever of essential importance in Egypt, is discussed at length. This, as also the drainage, is treated, first for Lower Egypt (pp. 1-117), and then for Upper Egypt (pp. 119-215). The Sudan irrigation is described on pp. 232-249. New works and general improvements have been established in all the sections.

OBITUARIES.

SIR EDGEWORTH DAVID, the famous Australian geologist and explorer in the Antarctic, died on August 28 at the age of seventy-six. He discovered the South Magnetic Pole, and was one of the first party to climb Mount Erebus.

DR. WILLIAM JAMES FISHER, lecturer on astronomy at Harvard Observatory, and earlier instructor in physics at Cornell University, died on September 2 at the age of sixty-six. His work involved the study of lunar eclipses and meteors.

DR. FRANK EVANS SEAGRAVE, the astronomer of Providence, R. I., died on August 15 in his seventy-fifth year. In 1882 he photographed a transit of Venus, and later (1909) foretold with accuracy the appearance of Halley's comet in 1910. He also studied minutely the eclipse of the sun in 1932.

DR. EDWARD R. BERRY, of Malden, Massachusetts, died on August 7, 1934. In 1924 he perfected the construction of the valuable lens of fused quartz.

DR. GEORGE CLINTON BRANDENBURG, of Purdue University, died on September 3 at the age of fifty-five. He was an able teacher, well known for his work as a psychologist.

DR. WILLIAM A. P. GRAHAM, associate professor of geology at the Ohio State University, died August 11 at the age of thirty-five. He also taught at the University of Iowa and Texas Technological College and at the time of his death was engaged in geological work in the Sweet Grass Hills in northern Montana.

DR. EDWIN WARD, director of the Royal Scottish Museum, Edinburgh, died on August 10 at the age of fifty-four.

PUBLICATIONS RECENTLY RECEIVED.

Richter's Organic Chemistry, Vol. I. Chemistry of the Aliphatic Series; translated by Eric N. Allott. Third edition. Philadelphia and London, 1934 (P. Blakiston's Son & Co., $10.00, and Kegan Paul, Trench, Trubner & Co.).

A Textbook of Organic Chemistry; Joseph S. Chamberlain. Third edition. Philadelphia, 1934 (P. Blakiston's Son & Co., $4.00).

A Textbook of Histology; by A. A. Maximow and W. Bloom. Philadelphia, 1934 (W. B. Saunders Co., $7.00).

Fog; by Alexander McAdie. New York, 1934 (The Macmillan Co., $2.50).

Smithsonian Miscellaneous Collections, Vol. 92, No. 8. Samuel Pierpont Langley; by C. G. Abbot.

The Fundamentals of Chemical Thermodynamics, Part II, Thermodynamical Functions and their Applications; by J. A. Y. Butler. London, 1934 (Macmillan and Co., $3.00).

The Diffraction of Light, X-Rays, and Material Particles; by C. F. Meyer. Chicago, 1934 (The University of Chicago Press, $5.00).

New Mexico School of Mines—Bulletin No. 10—The Geology and Ore Deposits of Sierra County, New Mexico; by G. T. Harley. Socorro, 1934 (State Bureau of Mines and Mineral Resources).

La Scienza Relativa All'Esperienza—Preliminari O Delia Matematica Relativa All'Esperienza; by Gaetano Ivaldi. Genoa, Italy, 1934 (Libraria Editrice Italia).

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PETROLOGY OF THE ALKALINE STOCK AT PLEASANT MOUNTAIN, MAINE

WILLIAM F. JENKS.

PART I.

INTRODUCTION.

In recent years considerable attention has been focused on the alkaline and associated intrusives of central New Hampshire. Largest of these masses is the White Mountain batholith, in which the most abundant rocks are granites and syenites. This body was described by Billings in 1928.[1] Around the White Mountain batholith numerous smaller areas of alkaline rocks have been described or briefly mentioned. Among the latter are two small isolated syenite areas, Pleasant Mountain and the Burnt Meadow Mountains, situated in western Maine southeast of the White Mountain intrusive complex. The geology of the Burnt Meadow Mountains has been mapped and studied by E. S. C. Smith, who as yet has not published his data.

Pleasant Mountain is located about halfway between Fryeburg and Bridgeton, Maine, near the intersection of latitude 44° north and longitude 70° 50′ west and is in the southeast corner of the Fryeburg sheet of the U. S. Geological Survey Atlas. The mountain rises to a number of ridges and peaks averaging 1900 feet above sea level, the highest reaching 2007 feet. The surrounding country, rather flat, has an average elevation of between 400 and 500 feet, giving a total relief to the mountain of some 1500 feet. The topography of the area is shown in Figure 1.

[1] Billings, M. P., The petrology of the North Conway quadrangle in the White Mountains of New Hampshire. Proc. Am. Acad. Sci., 63, 69-137, 1928.

Following a suggestion by Professor Marland Billings, the writer made a geological map of the mountain in the summer of 1931. The petrographic work was carried on during the winter of 1931-1932 and 1932-1933, and has benefited by constructive criticism of Professors E. S. Larsen and A. N. Winchell. Professor R. A. Daly kindly made available to the writer notes and specimens taken by him on a two-day reconnaissance trip in 1916.

There has been very little previous work on the geology of Pleasant Mountain. Hitchcock, in his "Geology of New Hampshire,"[2] mapped the mountain as syenite. No other material has been published about the stock. Professor E. S. C. Smith made a reconnaissance of the mountain, and his results have been briefly summarized by Toppan.[3]

In determining locations reliance was primarily placed in an aneroid barometer used in connection with an enlarged U. S. Geological Survey topographic map. An accuracy to within thirty feet vertically may be expected by this method, but the horizontal errors may be much larger, due to the considerable errors and omissions in the topographic map. To avoid this difficulty in some places location was established by means of a number of bearings on known points. Wherever possible, contacts were actually traced rather than located by a few cross-traverses.

GENERAL GEOLOGY.

The mountain is the outcrop of a number of syenitic intrusions constituting a composite stock which in ground-plan forms an irregular oval with its long axis striking about N. 20° E. The areal extent of the intrusives is 3.15 square miles (See Table III). The syenites are intrusive into a coarsely crystalline granite or granodiorite. Scattered remnants of volcanic rocks within the stock indicate that the plutonic phase was preceded by a period of volcanism. Many of the numerous basic dikes on the mountain are believed to be related to this early stage. The plutonic rocks of the stock have been divided into two stages on the basis of age relations. Each of these stages contains several rock types, some of which

[2] Hitchcock, C. H., The geology of New Hampshire. Part I, 1874, Part II, 1877, Parts III, IV, and V and Atlas, 1878.

[3] Toppan, F. W., The geology of Maine. Schenectady, N. Y., 1932. (Mimeographed thesis.)

are gradational into one another. Table I summarizes the intrusive history as interpreted by the writer.

TABLE I.

GEOLOGIC SEQUENCE.

Quaternary glaciation. Formation of till deposits and lake and river deposits in the surrounding country.
Period of alkaline intrusions, in three stages:
III. Nordmarkite, porphyritic hornblende syenite, fine pink porphyritic syenite, coarse anorthoclase syenite porphyry, aplite and bostonite dikes.
II. Analcite syenite, monzonite, diorite. Augite syenite porphyry, fine-grained gray porphyritic syenite, hybrid syenite.
I. Volcanics (trachytic tuffs, breccias, and flows). Dikes (lamprophyres, diorite, orthophyre, etc.).
Chatham granite.

CHATHAM GRANITE.

General relations. Completely surrounding the Pleasant Mountain stock is a coarse-grained granite or granodiorite believed to be the same as the Chatham group of intrusives of New Hampshire.[4] This tentative correlation is based on the lithologic similarity of the two rocks and on the presence of intermittent outcrops of similar rocks east from the Maine-New Hampshire boundary. The gneisses and schists into which the Chatham was intruded are absent in the vicinity of Pleasant Mountain.

In 1928 Billings believed the Chatham group to be Pre-Cambrian in age, granting the evidence was not conclusive.[5] His field work in the summer of 1932, however, disclosed the probability that most of the intrusives of central New Hampshire, including the Chatham, are Devonian or younger.[6] It may be said broadly that the Chatham group is post-Devonian, probably pre-Mesozoic.

Description. The Chatham varies from granite to granodiorite, with an average approaching an adamellite. It is a medium to coarse, hypidiomorphic-granular rock cut by pegmatitic and aplitic phases. Yellow-brown where weathered, it is gray on fresh, glacially scoured surfaces. White feldspar, gray glassy quartz, and muscovite and biotite in smaller amounts are the megascopic minerals. The biotite is always present and at some localities, especially on the eastern slope of

[4] Billings, M. P., Op. cit., p. 82.
[5] Billings, M. P., Op. cit., p. 89.
[6] Billings, M. P., personal communication.

the mountain, is segregated into attentuated schlieren. In contrast the muscovite is locally quite absent, notably near the stock along its western boundary. Accessory minerals include magnetite, apatite, zircon, hornblende, titanite, garnet and epidote. Variability in the composition of the granite is well shown by the Rosiwal analyses in the first three columns of Table II. The rapid change in feldspar composition is shown by columns 1 and 3, referring to specimens taken only 500 feet apart; in the field these phases appear very similar both as to texture and composition.

TABLE II.

Rosiwal Analyses.

	1	2	3
Quartz	18	33	33
Orthoclase	..	32	44
Microperthite	28	..	
Oligoclase	39	18	15
Muscovite	7	6	2
Biotite	7	11	5
Magnetite	..	tr.	1
Apatite	tr.	tr.	..
Zircon	..	..	tr.
Garnet	1	..	..
	100	100	100

1. Chatham granite. Stony Brook, elevation of 580 feet.
2. Chatham granite. Ledge in field southwest of mountain.
3. Chatham granite. Ridge south of Stony Brook at elevation of 740 feet.

All figures refer to volume per cents.

PART II.

PERIOD OF ALKALINE ERUPTIVITY.

Introduction. The various post-Chatham eruptives will be described in the approximate order of formation. Dike rocks will, however, be taken up together at the end of this section, since the range in their age is considerable. That the three stages in the eruptive history of the mountain overlap is undoubtedly true. For example, even while the plutonic phases were solidifying it is probable that there was strong volcanic activity at the surface.

Pleasant Mountain itself affords no evidence for determining the age of the alkaline intrusives. Consequently reliance must be had in correlation with similar intrusives of the New England-Quebec comagmatic province. Varying

conclusions have been reached as to the date of injection. Billings and O'Neill termed it Devonian.[7] Daly concluded that the alkaline rocks of Ascutney Mountain are post-Carboniferous and pre-Cretaceous.[8] Recent field work by Billings has led him to conclude that they are Carboniferous or younger,[9] while Katz calls the alkaline rocks of the Casco Bay region (Maine) Carboniferous.[10] For several reasons the Tertiary age of the Monteregian Hills has seemed probable to F. F. Osborne.[11] For the purpose of this paper it will be said that intrusives are probably of Mesozoic or early Cenozoic age.

The areas occupied by the various rock groups of the stock are listed in Table III.

TABLE III.

AREAS OCCUPIED BY THE VARIOUS ROCK GROUPS OF PLEASANT MOUNTAIN.

		Area in sq. miles	Per cent of whole stock
Stage I	Volcanics	.06	1.87
Stage II	Augite syenite, etc., of east side	.22	7.03
	Analcite syenite, with subordinate monzonite and diorite	.07	2.17
Stage III	Nordmarkite, etc.	2.59	82.50
	Anorthoclase syenite porphyry	.21	6.43
Total		3.15	100.00

Stage I. During the initial stage of activity the essential process was the eruption of fragmental and flow material, with accompanying injection of dikes into the country rock. The volcanic material is preserved only as great inclusions in the rocks of the two later stages (See Figures 2 and 3). Of the three types of observed volcanics—*tuffs, breccias,* and *trachyte porphyries*—the last two are of greatest importance.

Tuff occurs only on the north peak. It shows distinct bedding, a fine-grained horizon overlying a rather coarse crystal tuff. The contact between the beds strikes northwest and dips northeast. Both tuffs are trachytic in composition. The fine-grained upper bed consists of comminuted feldspar in the pro-

[7] Billings, M. P., Op. cit., p. 89.
O'Neill, J. J., St. Hilaire and Rougemont Mountains, Quebec. Can. Geol. Surv. Memoir, 43, 24, 1914.
[8] Daly, R. A., The Geology of Ascutney Mountain, Vermont. U. S. Geol. Surv. Bull. 209, 1903.
[9] Personal communication.
[10] Katz, F. J., U. S. Geol. Surv. Prof. Paper 109, 165-177, 1917.
[11] Personal communication.

portion of two-thirds orthoclase to one-third plagioclase (probably oligoclase). Small amounts of biotite, magnetite, and pyrite are present. Silicification is important, especially

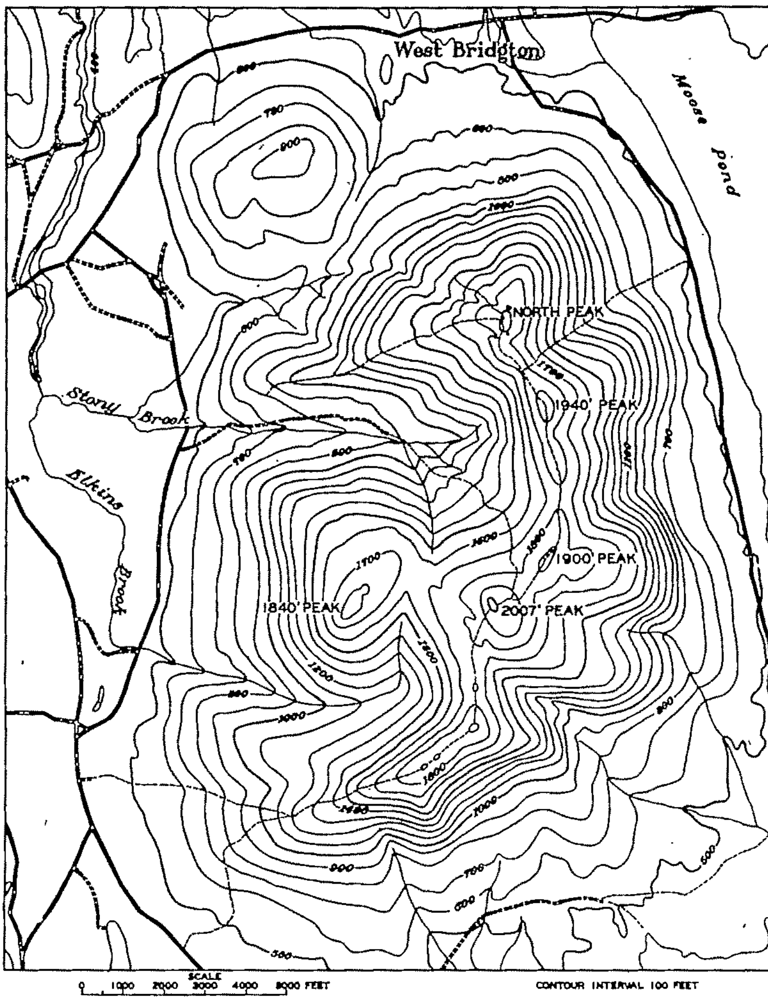

Fig. 1. Topographic map of Pleasant Mountain.

near the contacts. Accessory minerals are apatite, titanite, and zircon, in the order of decreasing abundance. The coarser tuff horizon, which makes up most of the xenolith, shows in

thin-section angular fragments of orthoclase, microperthite, oligoclase, andesine, quartz, and biotite, imbedded in a fine-grained orthoclase-rich matrix.

Trachyte porphyry makes up the whole of an inclusion in the augite syenite on 2007′ Peak and is also found on the north-

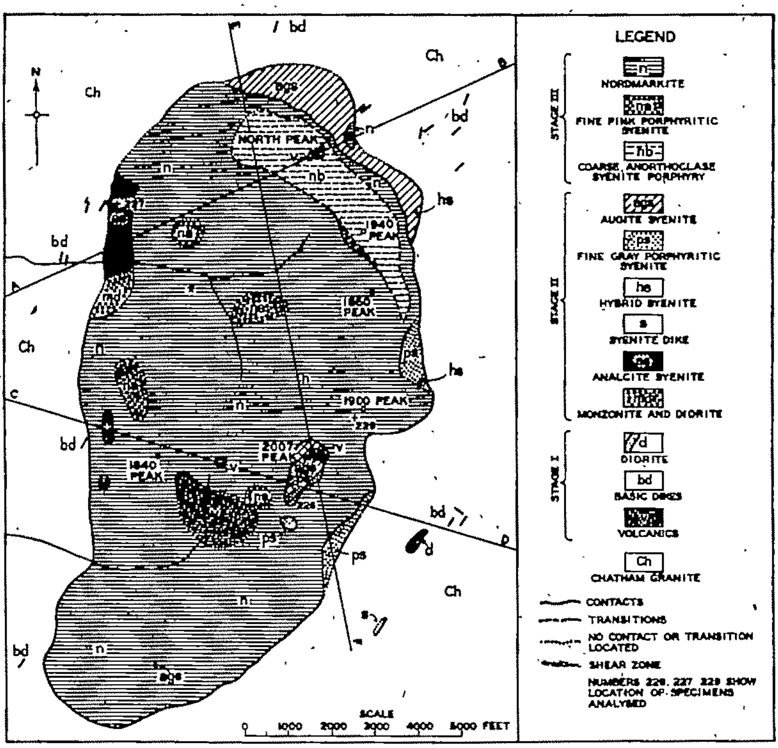

Fig. 2. Geologic map of Pleasant Mountain.

west slope of 1840′ Peak. The rock is gray, fine-grained, and spotted with angular pink and white feldspar phenocrysts, some of them over a centimeter long. Occasionally hornblende phenocrysts are visible. The feldspar phenocrysts are mostly subhedral to euhedral plagioclase varying from sodic labradorite to medium oligoclase, the average being a calcic oligoclase. A few phenocrysts are microperthite, always subhedral. Highly resorbed augite, hornblende, and biotite phenocrysts are common. The groundmass consists of short prisms of alkali feldspar, sometimes with a pronounced

trachytic texture, and is spotted with magnetite, minute biotite flakes and secondary hornblende. Quartz is rare, occurring only as very small interstitial grains. Apatite, titanite, and zircon are the accessory minerals.

Although the large area of volcanics in the valley of Elkins Brook is chiefly a breccia, it contains subordinate areas of trachyte porphyry more acid than that on 2007′ Peak. The phenocrysts are mostly antiperthite surrounded by orthoclase. There are a few small laths of andesine. Hornblende occurs sparingly as euhedral to subhedral phenocrysts, and is sometimes segregated into granular masses up to 1.5 cm. in diameter. The groundmass is similar to that described in the preceding paragraph.

The *breccias* which constitute most of the Elkins Brook volcanics and parts of the area of volcanic rocks on the west slope of 1840′ Peak are mottled gray rocks with more or less rounded fragments varying from pink to nearly black in color. Among the fragments, ranging in diameter from about 2 mm. up to about 10 cm., basaltic material is predominant. It is fine-grained and generally porphyritic. Apparently the fragments are parts of already consolidated lava caught up and carried away by the later extrusions. The material of the matrix resembles very much the groundmass of the unbrecciated flow rocks. All of the volcanics in the valley of Elkins Brook are more or less indurated with pyrite, which is present in definite veins or less frequently as euhedral crystals.

Stage II. The second stage of magmatic activity on Pleasant Mountain is represented by plutonic rocks of which numerous remnants have been preserved through the final eruptive period. Rocks of Stage II occur as elongated bodies at the edge of the stock, or as inclusions in the rocks of stage III. On the east side of the stock the rocks belong to a series of syenites characterized by the presence of augite. This series contains three types: an augite syenite porphyry, a fine-grained gray porphyritic syenite, and a hybrid syenite of variable composition. Contacts between types of this series are always highly irregular, showing a commingling of two rather similar magmas during the final period of crystallization. It is for this reason that in the geological map (Figure 2) the symbol for fine-grained gray porphyritic syenite is superimposed on that of the augite syenite porphyry. The hybrid syenite is a case of extremely close mingling of these related magmas, together with some slight impregnation by a magma similar to the nordmarkite of Stage III. Age relations

in one outcrop of the hybrid rock are reversed in the next, showing the close temporal relation of the constituent magmas. The two important areas of hybrid syenite are indicated on the map by arrows only, since their boundaries are arbitrary.

The feldspars of the *augite syenite porphyry* are orthoclase, microperthite, and oligoclase. The latter is present as irregular resorbed phenocrysts, some of them definitely zonal. In

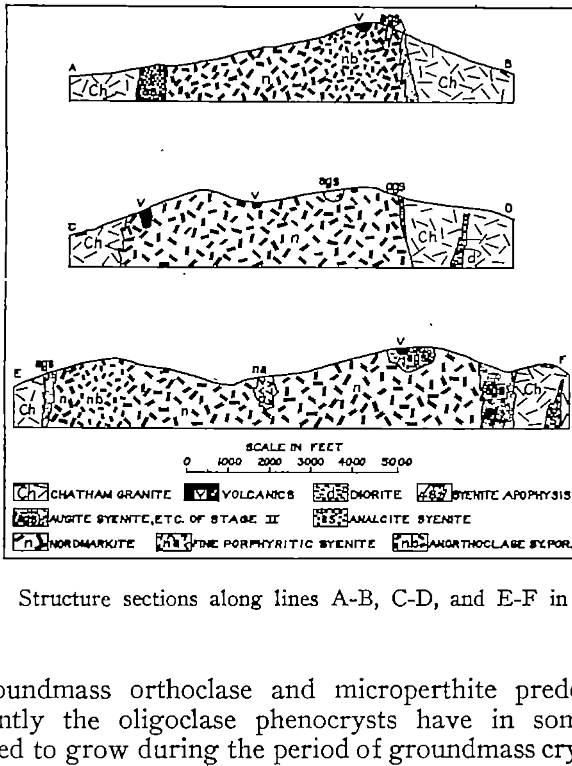

Fig. 3. Structure sections along lines A-B, C-D, and E-F in Figure 2.

the groundmass orthoclase and microperthite predominate. Apparently the oligoclase phenocrysts have in some cases continued to grow during the period of groundmass crystallization, for the granular orthoclase of the groundmass is intergrown at the phenocryst borders with the plagioclase of the phenocrysts. Augite is the most important mafic mineral, as shown by the Rosiwal analysis in column 4 of Table VI. It occurs as zoned and twinned euhedral pale green phenocrysts and as small rounded grains in the groundmass. Hornblende and biotite are most prominent as ragged grains in the groundmass, but there is also an occasional phenocryst of biotite. Where quartz occurs it is as small interstitial patches. Magnetite, apatite, and zircon are the only accessories.

The *fine-grained porphyritic syenite* differs from the augite syenite porphyry in the nature of the phenocrysts and in the amount of augite. Phenocrysts vary from andesine to sodic oligoclase, the more calcic feldspars in places being surrounded by an irregular rim of untwinned oligoclase. Where augite occurs it is both as resorbed, magnetite-spotted phenocrysts and as small grains in the groundmass.

A chemical analysis of this fine porphyritic syenite is given in column 226 of Table IV, and a Rosiwal analysis of the same sample is to be found in Table VI. For location of specimen see Figure 2. In Table V is given its norm.

TABLE IV.

Chemical analyses.

	226	227	A	229	B	C	D
SiO_2	59.96	60.96	58.30	63.32	63.20	64.88	62.24
Al_2O_3	17.73	19.20	21.38	18.75	17.45	16.24	15.82
Fe_2O_3	2.20	1.24	1.05	1.24	3.60	1.37	1.94
FeO	2.97	1.63	2.04	1.77	n.d.	2.70	4.69
MgO	1.57	.55	.22	.71	.75	.89	.07
CaO	3.07	1.86	.95	2.03	1.46	1.92	2.65
Na_2O	5.90	7.07	8.66	6.04	6.90	5.00	4.80
K_2O	4.18	5.54	6.06	4.88	5.88	5.61	6.26
H_2O+	.29	.58	.45	.36	.50	.46	.56
H_2O-	.08	.04	.35	.06	...	.19	.07
CO_2	...	.08	none	.10	...	none	...
TiO_2	1.15	.60	.10	.52	.46	.69	.87
ZrO_2	.05	.07	.02	.05	...	.13	...
P_2O_5	.37	.14	.04	.16	...	.13	.14
MnO	.18	.18	tr.	.11	...	.14	.24
SrO	.01	none	...	.03	...	...	...
BaO	.13	.06	none	.11	...	.06	...
Cl	...	...	.35	...	...	.04	...
F	...	...	...	...	...	.08	...
SO_3	...	...	.08	...	...	...	...
FeS_2	...	...	...	...	...	none	...
NiO	...	...	...	...	...	none	...
	99.84	99.80	100.05	100.24	100.14	100.53	100.35

226. Fine-grained porphyritic syenite of Stage II. 1000 ft. SSW of 2007′ Peak. R. B. Ellestad, analyst.
227. Analcite syenite. Elevation of 1050 ft. along crest of ridge north of Stony Brook. R. B. Ellestad, analyst.
A. Nephelite syenite, Red Hill, N. H. Described by Pirsson and Washington, this Journal, 23, 273, 1907.
229. Nordmarkite. 1500 ft. northeast of 2007′ Peak. T. Kameda, analyst.
B. Nordmarkite. Tonsenås, near Christiania, Norway. From U. S. Geol. Surv. Prof. Paper 99. G. Forsberg, analyst. Described by Brögger.
C. Nordmarkite. Mt. Ascutney, Vt. From U. S. Geol. Surv. Prof. Paper 99. W. F. Hillebrande, analyst. Described by Daly.
D. Nordmarkite. Chandler Mt., N. H. Described by Billings. S. Parker, analyst.

TABLE V.

Norms of analysed rocks.

Name	226 Laurvikose	227 Nordmarkose	229 Laurvikose
Symbol	I(II).5.2."4.	I"."5.1"."4.	I.5."2.(3)4.
Quartz	2.34	....	3.72
Orthoclase	25.02	32.80	28.91
Albite	49.78	48.21	50.83
Anorthite	9.45	4.17	9.45
Nepheline	....	6.25	....
Diopside	2.38	3.68	.22
Hypersthene	3.06	....	3.15
Olivine	....	.66	....
Magnetite	3.25	1.86	1.86
Ilmenite	2.13	1.22	.91
Apatite	1.01	....	....
	98.42	98.85	99.05

In the outcrop the *hybrid syenite* of Stage II is extremely spotty in appearance. Medium-grained, gray augite syenites, both porphyritic and non-porphyritic, are thoroughly intermingled with nordmarkite of varying texture. Close commingling of the magmas during consolidation is reflected by the variation of texture and mineralogical compositions in different specimens.

On the western slope of the mountain is a narrow north-south belt of rocks definitely older than the central mass of nordmarkite. These rocks are intrusive into the Chatham granite on the west, while to the east they are cut by intrusives of the final plutonic stage. There are present in this belt three types: *analcite syenite, monzonite,* and *diorite,* of which the first is by far the most extensive. The relative ages of these three types could not be precisely determined. The monzonite grades into the diorite and is probably essentially contemporaneous with it.

The *analcite syenite* is a medium to coarse-grained light gray rock spotted abundantly with black amphibole. The rock is allotriomorphic and inequigranular. The prominent feldspar is microperthite, but a few of the small feldspars are oligoclase about $An_{27}Ab_{78}$, showing albite twinning. Analcite is always present to the extent of six to eight per cent and occurs in small rounded grains imbedded in the feldspar or interstitial to it. The hornblende, in subhedral to anhedral grains, is somewhat darker than that found in the rest of the stock. It is strongly pleochroic with X = pale greenish

TABLE VI.

Rosiwal Analyses.

	4	226	227	5	6	7	8	9	229	10	11	12
Quartz	..	..	..	..	..	..	..	7	3	3	3	..
Orthoclase	58	..	..	..	..	..	..	74	..	..	43	51
Microperthite	..	..	..	..	..	40	..		83	79	45	..
Oligoclase	20	..	3	3	..	..	..	11	7	15	..	..
Andesine	..	5	..	..	..	..	..	..	..	..	..	..
Alkali feldspar	..	80	80	82	84	..	..	..	..	..	..	..
Plagioclase (strongly zoned)	..	..	..	..	..	47	62	..	..	..	..	..
Analcite	..	..	7	7	8	..	..	..	..	..	..	..
Green hornblende	6	7	7	5	5	..	..	2	tr.	1	2	20
Brown hornblende	..	..	..	..	..	..	..	..	..	..	..	27
Muscovite	..	..	..	..	..	..	..	..	..	..	..	..
Biotite	1	1	..	..	..	8	18	2	2	2	4	..
Augite	11	3	..	..	..	2	15	..	1	tr.	2	1
Magnetite	3	4	1	tr.	1	1	4	3	3	tr.	1	1
Apatite	1	tr.	tr.	1	tr.	2	1	1	tr.	tr.	tr.	tr.
Titanite	..	tr.	2	2	2	tr.	tr.	tr.	1	tr.	tr.	..
Zircon	..	..	tr.	tr.	..	..	..	tr.	tr.	tr.	..	..
Garnet	..	..	..	..	..	..	..	..	..	..	..	..
	100	100	100	100	100	100	100	100	100	100	100	100

4. Augite syenite porphyry of Stage II. North slope of North Peak.
226. Fine-grained porphyritic syenite of Stage II. 1000 feet S.SW. of 2007′ Peak. See chemical analysis.
227. Analcite syenite. Elevation of 1050 feet along crest of ridge north of Stony Brook. See chemical analysis.
5. Analcite syenite. North slope of ridge north of Stony Brook.
6. Analcite syenite. 150 feet east of No. 5.
7. Monzonite. Elevation of 1000 feet, gully south of Stony Brook.
8. Diorite. Elevation of 1070 feet, gully south of Stony Brook.
9. Nordmarkite. Crest of northwest ridge, elevation of 1120 feet.
229. Nordmarkite. 1500 feet northeast of 2007′ Peak. See chemical analysis.
10. Nordmarkite. North fork of Stony Brook at elevation of 1720 feet.
11. Fine-grained porphyritic syenite of Stage III. North slope of 1840′ Peak.
12. Vogesite dike. Cuts the Chatham granite on the east slope of the mountain.
All figures refer to volume per cents.

brown, Y = pale olive green, and Z = dark blue green. Of the accessories titanite is common in crystals ranging up to one millimeter across. Zircon and apatite are persistently present in small amounts. Rarely allanite is found, occurring in small, nearly isotropic, red grains generally imbedded in the hornblende.

The constancy of mineral composition throughout the analcite syenite is brought out by the three Rosiwal analyses, Nos. 227, 5, and 6 in Table VI. In Table IV is given the chemical analysis and in Table V the norm of specimen 227. A chemical resemblance to the nephelite syenite of Red Hill, N. H. (Table IV, column A), is noteworthy.

The small areas of *monzonite* and *diorite* are immediately south of the elongated analcite syenite body. The typical monzonite in hand specimen is gray and of a uniform granitic texture. The feldspar consists of plagioclase and microperthite in about equal proportions. The former averages a calcic oligoclase, but is distinctly zoned. The augite (see Table VI, column 7) is in pale green, faintly pleochroic, anhedral grains, some of them showing multiple twinning. Titanite is commonly seen surrounding ilmenite or titaniferous magnetite grains.

With the change from monzonite to diorite there is a gradual increase in the mafic mineral content. In the diorite prominent flaky biotite in broad flat surfaces (up to 2 cm. across) haphazardly scattered through the rock produces a striking effect. The biotite is of the strongly pleochroic variety found in the monzonite, and contains rounded inclusions of magnetite (or ilmenite), apatite, titanite, and augite. Augite is also plentiful as subhedral to anhedral grains, rimmed in some sections with pale green fibrous uralite. The dominant feldspar is andesine with fine albite twinning lamellae. Accessory titanite occurs as in the monzonite, and also as minute veinlets visible in hand specimen.

Stage III. The final stage is especially interesting because of the variability of, and gradations among, its rocks. In most places where two types are observed together the contacts are transitional. By this is meant that through a zone ten to thirty feet broad there is a gradual change from the texture and mineral composition of one to the texture and mineral composition of the other. In contrast to this type of relation the southwestern contact of the coarse anorthoclase syenite porphyry, where it crosses the ridge between 1940′ and 1880′

Peaks, and for 2000 feet to the northwest, is sharp. Elsewhere, however, there is an observed transition between the two types. The distribution of the intrusives of Stage III is best seen by reference to the geological map (Figure 2).

In fresh specimens the ***nordmarkite*** is light gray and coarsely crystalline. It consists dominantly of feldspar, scattered dark green hornblende, and gray interstitial quartz. The rock has a medium to coarse-grained allotriomorphic texture in places distinctly porphyritic. It consists of varying proportions of microperthite, orthoclase, oligoclase, biotite, hornblende, and quartz, with magnetite, apatite, titanite, and zircon as accessories. In a few sections andesine or microcline or augite are present. In Table VI, columns 9, 229, and 10, are given the Rosiwal analyses of several specimens of nordmarkite. The variation in the quartz content is specially notable. The plagioclase is usually a sodic oligoclase, but in some of the specimens andesine is present in small amounts. The oligoclase, often subhedral in habit, is commonly surrounded by a zone of orthoclase, microperthite, or rarely antiperthite. Quartz occupies small interstitial areas or is present as round grains imbedded in alkali feldspar. In a few cases the inter-

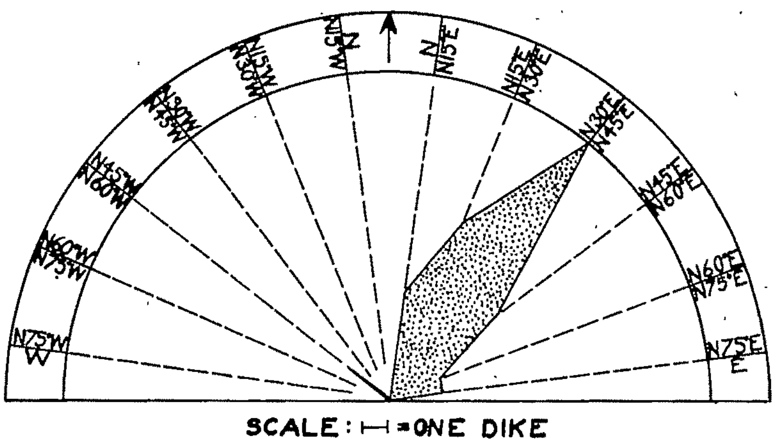

Fig. 4. Diagram to show the distribution of the strikes of 34 basic dikes on Pleasant Mountain. The number of dikes in every 15 degrees is plotted radially along the dashed lines. The limits of the 15 degree sector for each line are given at the circumference.

stitial areas are filled with micropegmatitic intergrowths of quartz and orthoclase in about equal amounts.

The important mafic minerals are hornblende and biotite, the former occurring in subhedral to anhedral grains which are considerably resorbed. The hornblende is pleochroic with the formula: X = pale yellow green, Y = olive green, Z = deep green. Indexes and birefringence of different grains of the mineral vary widely, as determined on the universal stage by the double variation method. Such variations probably indicate differences in chemical composition or state of oxidation, caused either by alteration or by zoning. As an example of the variation in optical properties in different hornblende grains from the same specimen, Table VII is given below. It will be noted that the birefringence of the two grains differs by .07, or approximately one-third of the total birefringence.

TABLE VII.

Optical properties of two grains of hornblende from the same specimen of nordmarkite, from elevation 1340 ft., east trail to the northern peaks.

A.

	α	β	γ	$\gamma-\alpha$	2V (—) observed	2V calculated
F	1.660	1.674	1.684	.024		76°
D	1.652	1.667	1.676	.024	70°	75°
C	1.649	1.664	1.673	.024		75°
F—C	.011	.010	.011			

B.

	α	β	γ	$\gamma-\alpha$	2V (—) observed	2V calculated
F	1.670	1.680	1.686	.017		71°
D	1.653	1.665	1.671	.017	62°	70°
C	1.647	1.659	1.664	.017		69°
F—C	.023	.021	.021			

All readings ± .002.

Biotite is present in subhedral resorbed flakes with orthoclase-filled embayments. In exceptional cases, the biotite is euhedral, showing perfectly hexagonal basal plates. Optical properties of the biotite are as follows: for white light, $\beta = 1.646$, $\gamma = 1.649$, both $\pm .001$, and $2V = 5°$ to $10°$. Sagenitic rutile has commonly developed within the biotite. In most cases the biotite formed after the hornblende, but a contemporaneous growth is sometimes apparent. The accessory minerals are those generally present in the stock: magnetite, apatite, titanite, and zircon.

In Table IV is given the chemical analysis of a specimen (229) of the nordmarkite, with the analyses (columns B, C, and D) of three other nordmarkites for comparison. The norm is given in Table V.

The *fine-grained porphyritic syenite* of Stage III is pink, buff or light gray. In the fresh specimen the phenocrysts appear gray and glassy. They are small and angular, aver-

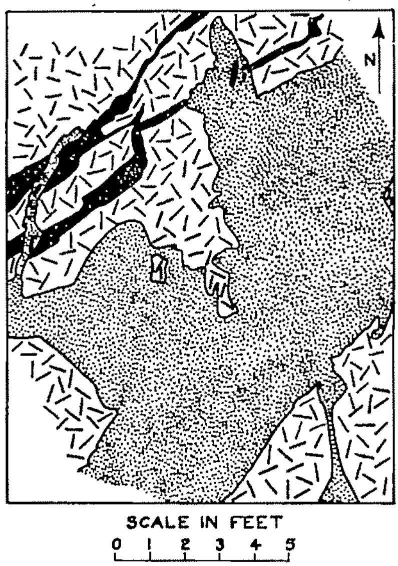

Fig. 5. Detail of an apophysis from the analcite syenite to show the effects of differential assimilation. Legend: Line pattern = Chatham granite, black = diorite dike, dotted = syenite.

aging two to three millimeters across. The commonest phenocryst is orthoclase in subhedral crystals showing Carlsbad twinning. Some phenocrysts, less regular in shape, are microperthite commonly surrounded by a rim of later pure orthoclase which is intergrown with the groundmass. Other phenocrysts together make up 30 to 35 per cent of the rock. The groundmass is generally an allotriomorphic intergrowth of equidimensional orthoclase grains. The amount of quartz present is very variable. It may be practically lacking or it may comprise 15 per cent of the groundmass as interstitial areas. In the groundmass are abundant needles of apparently

secondary hornblende. The elliptical body of fine porphyritic syenite on the northwest slope of 1840′ Peak is unusual in being abundantly spotted with miarolitic cavities containing inpointing quartz crystals. Magnetite and apatite are the only persistent accessories, while titanite is rare and zircon does not occur.

The *coarse anorthoclase syenite porphyry,* forming a crescentic body over the northern peaks, contains throughout a considerable proportion of anorthoclase or microperthite phenocrysts, generally well formed crystals. These phenocrysts average about one inch in length and show a pale blue schiller effect. This phenomenon is probably due to the faint but typical lattice of multiple twinning visible under the microscope. The anorthoclase varies greatly in optic angle, from 48° to 76°, but the indexes are consistently low. Table VIII is a summary of the optical data on some material with a relatively high optic angle.

TABLE VIII.

Optical properties of anorthoclase from anorthoclase syenite porphyry.

	α	β	γ	$\gamma-\alpha$	2V (—) observed	2V calculated
F	1.5300	1.5337	1.5363	.0063		81°
D	1.5236	1.5272	1.5299	.0063	76°	80°
C	1.5210	1.5246	1.5272	.0062		80°
F—C	.0091	.0091	.0091			

All readings ± .0007.

The groundmass of the anorthoclase syenite porphyry is similar to the nordmarkite, with the same variations in texture and feldspar content. One phase of this porphyry is characterized by a finer-grained, gray groundmass and somewhat smaller phenocrysts. It is this phase in which most of the shearing south and west of 1940′ Peak occurs.

Dike rocks. Associated with the Pleasant Mountain syenites are four distinct types of dike rocks: 1, lamprophyres, orthophyres, etc.; 2, diorites; 3, bostonites and aplites; 4, syenite. The lamprophyres and diorites are generally early, cutting only the Chatham granite, and are cut in turn by bostonites and aplites. The bostonites and aplites are often found cutting the latest of the plutonic intrusives, suggesting a trend

from basic to acid in dike-rock composition as the irruptivity progressed.

The lamprophyres *vogesite* and *kersantite*, both dense dark gray to black rocks intruding the granite, are common. An abundance of long needles of brown hornblende makes the vogesite a rather striking rock in thin section. A Rosiwal analysis of it is given in Table VI, column 12. Only one *camptonite* dike was discovered. The diorite dikes usually resemble the lamprophyres in color, but variations in texture are more common, especially in the larger dikes. The diorite intrusion in the granite southeast of 2007′ Peak is considerably larger than any other dikes of the region, being some hundred feet across and about six hundred feet long. Hornblende, chlorite, and vestiges of pyroxene comprise the mafic mineral content.

Relatively unimportant among the earlier dike rocks is *analcite orthophyre*, a fine-grained, non-porphyritic rock studded with abundant spots of black hornblende. One of the last minerals to form was analcite. The approximate volume composition of the orthophyre is: orthoclase 63 per cent, albite 15 per cent, analcite 7 per cent, hornblende 10 per cent, magnetite 3 per cent, augite, biotite, apatite, and titanite 2 per cent.

The *bostonite* and *aplite* dikes, both within the stock and in the Chatham granite, have the usual petrography of such rocks. The syenite dike on the southeast slope of the mountain may be regarded as an apophysis from one of the main syenite intrusions and is arbitrarily grouped with Stage II in the geological map.

Most of the dikes are nearly vertical, a dip as low as 70° being unusual. Their most interesting structural feature is uniformity of strike, a feature brought out in the accompanying diagram, showing the strikes of some 34 lamprophyre and diorite dikes (Figure 4). (The aplites and bostonites are quite haphazard in trend.) The average strike is N. 38° E., a figure which approximates the maximum number in the strike diagram.

Mechanics of Injection.

It may be pointed out briefly that the injection of the Pleasant Mountain syenites could have been effected either by a modified ring-fracture mechanism or by piecemeal stoping

with abyssal assimilation. Ring dikes may be embayed or completely obliterated by later intrusions, and the final injection may have a form not dike-like but rather stock-shaped, due to the sinking of the whole central block. Thus the rocks of Stage II could be remnants of early ring dikes with the nordmarkite taking the place of the subsided central block. Or the magmas of Stage II, having first worked their way upward by stoping, solidified and were in turn stoped into by the rising magma of the final stage. It is possible that a combination of the two mechanisms is the true solution of the problem.

Although the outer contact is sharp throughout most of its length, the effects of marginal assimilation were observed in several places. A detailed plan of an apophysis from the analcite syenite which shows definite differential assimilation is given in Figure 5. That the apophysis was intruded by assimilation is suggested by the irregular shape of the body, by the presence of quartz instead of analcite in it, and by the poorly defined contacts between it and the granite. The removal of the granite from around the rotated fragments of the diorite dike point clearly to the action of differential assimilation. The explanation of this phenomenon is probably that the syenitic magma stood higher in the reaction series than the granite, but lower than the diorite. Hence, if no superheat is invoked, only the granite could be attacked. Very probably the water content of the syenitic magma was high, greatly increasing the speed of solution.

Intimately connected with the problem of the mechanics of injection is the problem of the kind and distribution of inclusions. Already there have been described the large xenoliths of volcanic material. In addition there are irregularly scattered through the nordmarkite and plutonic porphyries small rounded inclusions, the petrography of which is similar to that of the trachyte-flow rocks of the summit (2007′ Peak) inclusion. Why xenoliths of the Chatham granite are rare is difficult of explanation, but it is possible that during the late plutonic activity the upper part of the stock had worked its way well into the volcanics erupted at an earlier stage. The granite walls of the stock being essentially vertical would then have suffered a minimum of stoping, while the poorly supported roof of volcanics would have supplied a maximum of stoped blocks.

Conclusion.

A point that must be emphasized again in concluding is the extreme diversity in composition and especially in the texture of the rocks which comprise the alkaline eruptives. While among the plutonic rocks two definite intrusive stages can be distinguished, age relations of individual types within each stage are obscure. Although the stoping hypothesis is preferred by the writer to explain the emplacement of the syenites, the ring-fracture hypothesis will likewise satisfy the facts related to the problem. That marginal assimilation played a definite, though small, rôle is clear, a fact illustrated by the example of differential assimilation cited. No attempt is made to explain the origin of the post-Chatham magmas.

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THE MAGMATIC WEDGE.

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Present conditions in the crust suggest and the geological record of past conditions affirms the conclusion that magmas are locally formed and locally intruded. Yet there is no generally accepted explanation as to why magmas should rise in restricted regions throughout vast intervals of time and why other regions should be unvisited by intrusions or extrusions during even greater intervals. The circum-Pacific belt of Tertiary intrusion is an instance of the former and the Pre-Cambrian shield of North America exemplifies the latter type of region. Because these conditions seem to be anomalous under accepted theories, the writer attempted an explanation in a recent paper.[1] The suggestion, there made, is that magmas are generated under wide regions but rise in restricted belts, having been propelled toward lines of weakness by crustal subsidence. Isostatic maladjustments caused by distortion in the deeper levels of the earth lead to subsidence. This mechanism was originally[2] approached from the demands of effects: crustal structures appear to demand this or a similar mechanism. In the present paper the writer attempts to show that the same mechanism is indicated by an appeal to the most reliable geophysical data and cognate geological evidence.

The commonest conception of geoisotherms and, so far as can be seen at present, the correct one, is that they are symmetrically concentric in the interior and that at shallow depths, as indicated by the variable geothermal gradients, they are extremely irregular surfaces. At depths less than a few hundred kilometres there is expected to be a zone of transition between irregular isotherms above and the smooth ones below.

It is generally accepted that heat is developed in considerable quantities in the crust and in smaller amounts in the sub-crust by the breaking down of radioactive materials. These materials are not evenly distributed and, where they are concentrated, it is considered probable that heat will be generated faster than it can be removed by conduction. The writer has

[1] DeLury, J. S., The Thermal History of the Crust, Trans. Roy. Soc. of Canada, 3d Ser., 26, Sect. 4, pp. 277-88, 1932.

[2] DeLury, J. S., The Auto-Traction Hypothesis of Crustal Evolution, Contrib. from Dept. of Geol., University of Manitoba, 1931.

already emphasized the importance of crustal subsidence as a source of heat for the raising of temperature and the production of magma in the sub-crust.[3] It was shown that if a crust 50 miles thick subsides 100 feet, the heat equivalent of the subsidence will warm and liquefy a subjacent thickness of about 90 feet of rock which before the subsidence had a temperature 400° C. below that of liquefaction. There are considered, therefore, to be two very important sources of energy for local heat development in crust and shallower sub-crust. The development of heat locally is involved necessarily with the variations in steepness of geothermal gradients from place to place, or, in other words, with the irregularities of the geoisotherms.

THERMAL GRADIENTS.

For reasons peculiarly their own, geophysicists[4] have been tempted to use an average temperature gradient, corresponding to a rise of about 30° C. per kilometre of depth, to depict the thermal curve at shallow depths and to meet the gradient which is calculated to hold for the interior of the earth. The difficulties which lie in the way of securing an average gradient are apparent and are usually indicated. Radioactive elements are not evenly distributed in the crust. Conductivity varies somewhat from place to place. Magmas rise in the crust and bring heat from unknown sources. No submarine thermal gradients are known. The writer suggests that in the search for an *average* gradient, the significance of the *variation* of the gradient has been lost sight of.

The facts concerning the variation in thermal gradient from place to place, as conveyed in Table I, are striking. In places in the North American shield the gradients are only *one-fourth* of that used by geophysicists when plotting the gradient of the earth. The average from the shield may be less than *one-third* of the average commonly used for the whole earth.

[3] DeLury, J. S., Magmas from Subsidence, this Journal, 23, pp. 357-68, 1932.

[4] Jeffreys, Harold, The Earth, p. 153, 1929.

Adams, L. H., Temperatures at Moderate Depths Within the Earth, Jour. Wash. Acad. of Sciences, vol. 14, p. 471, 1924.

Holmes, Arthur, Radioactivity and the Earth's Thermal History, Geol. Mag., vol. 62, p. 506, 1925.

Daly, R. A., Our Mobile Earth, pp. 112-4, comments significantly on the variations in thermal gradients, 1926.

Grout, F. F., Petrography and Petrology, gives an interesting discussion of the thermal gradient and uses a very suggestive diagram (p. 156), 1932.

That the shield is not exceptional is indicated by the gradients from the Transvaal mines. It is reasonably safe to infer that, had northern Ontario been the centre of civilization in place of western Europe, geophysicists would now be projecting gradients of 8° or 10° C. per kilometre in place of the one now used, namely 30°. Moreover, the gradients secured from Ontario gold mines are perhaps the safest of all to use. They are measured in unweathered crystalline rocks which are relatively impermeable to migrating waters and which have heat diffusivity best comparable to deeper rocks in the crust.

TABLE I.

(Approximate thermal gradients expressed by the rise in temperature in degrees C. with increase of 1 kilometre depth.)

No. 1	Idria mines, Austria	96
2	Average in common use	30
3	Average of eastern United States	24
4	Bendigo and Ballarat, Australia	22
5	Calumet and Hecla mine, Michigan	17
6	Average of 6 shafts, Kirkland Lake, Ontario	11½
7	Lowest from Kirkland Lake, Ontario	10
8	Frood mine, Sudbury, Ontario	10
9	Dome mine, Ontario	9
10	Hollinger mine, Ontario	8
11	McIntyre mine, Ontario	7½
12	Transvaal mines, South Africa	8½–7

(Numbers 1, 4, 5, and 12 are adapted from Lindgren's *Mineral Deposits.* Number 2 is near the average used by Adams, Holmes, and Jeffreys. Number 3 is adapted from Daly's *Mobile Earth.* Records for the Ontario mines were secured through the kindness of D. G. Sinclair, Chief Inspector of Mines, Ontario.)

To arrive at a correct basis for the discussion of geothermal gradients, a hypothetical case is chosen and illustrated in Figure 1. A centric cross-section of a sphere is shown. H and H′ are centres from which heat is conducted outward, and inward and outward, respectively, through the sphere. If H were the only centre of dispersion in the homogeneous sphere, the isothermal surfaces, represented by the concentric lines, would be perfectly spherical, but the centre, H′, close to the surface, has the effect of distorting the isotherms about H. If thermal gradients could be secured from shallow depths in the sphere, they would be found to vary. The highest would be secured above H′ and the lowest at places remote from the influence of H′. The lowest gradient (near T2) would be the one from which to extrapolate to ascertain

temperatures at depth. Gradient T1 would be too high for this purpose. Along T3 temperature would rise rapidly with

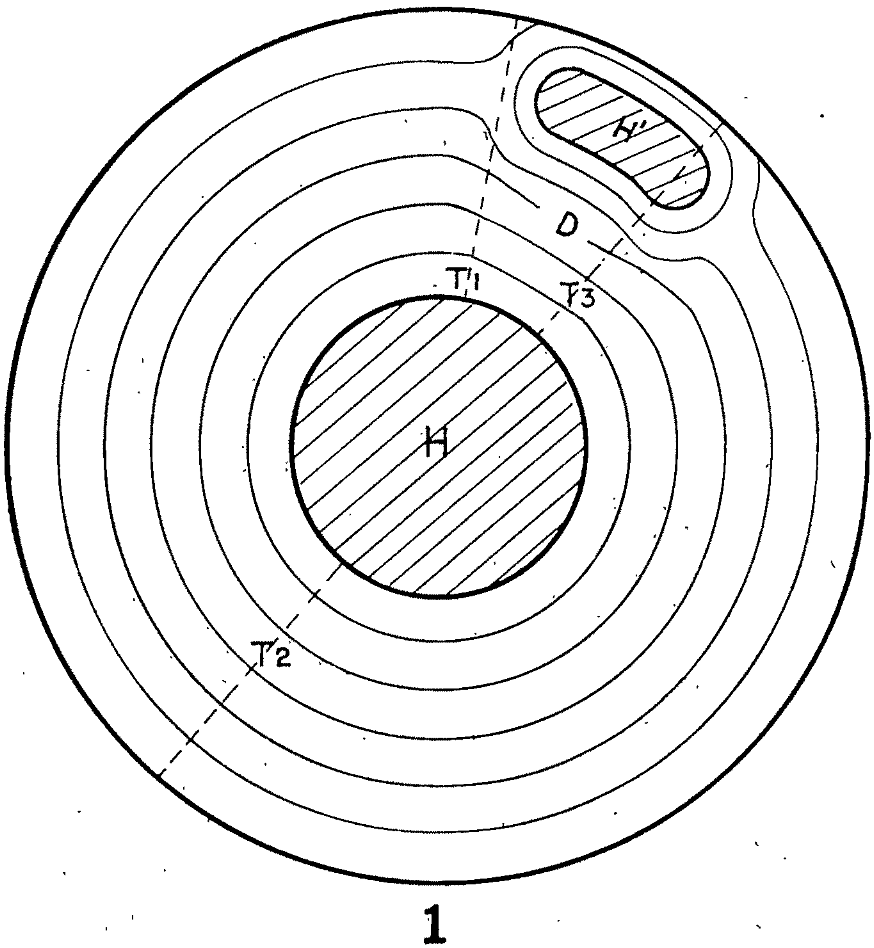

Fig. 1. Section of a hypothetical sphere with central and shallow sources of heat, H and H' respectively.

depth and below H' would fall off to suffer a relative rise again as H is approached. It is assumed, of course, that H and H' have not been diffusing heat long enough to equalize temperatures between them. If now the various temperature

gradients from the outer shell of the sphere were plotted on a depth-temperature diagram, extreme variations would appear, as shown by the gradients in Figure 2. On such a diagram all gradients would join at a level where H is approached, or more definitely, at a level where the isothermal surfaces are uninfluenced by H′. Clearly, the high gradients, no matter how irregular they may be, must approach the low gradient at depth, as indicated in the case of the earth in Figure 2.

Another significant deduction is obvious from Figure 1. The region under H′ with D as centre is expanded in contrast with similar regions which are not under the influence of H′. In other words, a sphere with two centres of heat generation like H and H′ suffers a thermal distortion. This and the preceding simple deductions are applicable to the earth.

An average geothermal gradient, could such be even remotely determined from the limited data, would be of great interest in permitting an estimate of the heat lost by the earth. The use of an average gradient to project into the depths for the purpose either of estimating temperatures in the interior, or of meeting a gradient which is estimated as holding there from other methods of approach, is bound to be misleading. The *lowest* gradient obtainable is the logical one to project, until such a time at least when it can be demonstrated that the lowness of the gradient is due to local causes. The possibility that endothermic molecular changes might be a disturbing factor, seems remote. Table 1 shows clearly that there is enough variation in the thermal gradient from region to region to require a serious explanation. Whether this variation is cause or effect, it may help to solve the mysteries of crustal mechanics. *It is likely both cause and effect.*

Figure 2 emphasizes graphically the importance and significance of the horizontal variation in the thermal condition of the crust. Curve 1 corresponds to a gradient of 6° C. per kilometre. Curve 2 illustrates a gradient of about 8° or the lowest from Ontario mines. It is considered that gradient 2 is still higher than the theoretically lowest because there is bound to be some radiothermal energy in the crust beneath the Ontario mines. Gradient 3 approximates the one used commonly by geophysicists and it is projected by them along the course indicated by 3′. Curve 4 indicates a gradient of 60° per kilometre. Much higher gradients, typical of Hinge zone areas, are not drawn. Curves 2, 3, and 4 must be accommodated to the conditions laid down by Curve 1 and must

approach the latter at depth-levels where the geoisotherms become smooth. The forms of 3″ and 4′ depend upon many factors but notably on the rate of generation of heat in higher levels as compared with the rate of flow from the deeper interior. The determining factors may decide that Curve 4 take the course 4″ rather than that indicated by 4′, in which

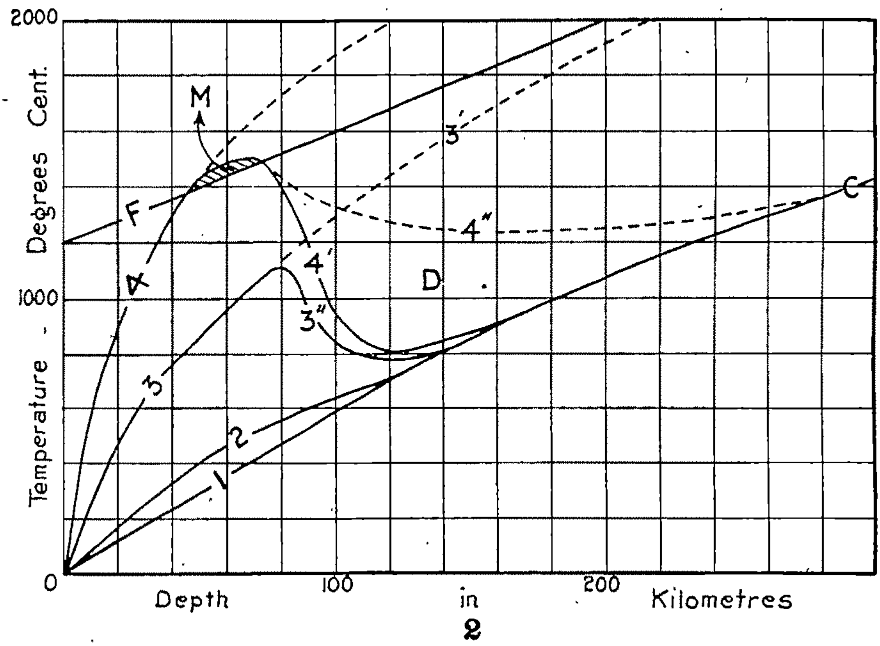

Fig. 2. Geothermal gradients and the fusion curve.

case there would be greater thermal expansion in the region D between levels of 60 and 300 kilometres. Assuming a coefficient of cubical expansion of .00002 and that a zone 300 kilometres thick suffers a rise of temperature of 400°, expansion upward would amount to more than 2 kilometres. In other words, a crustal bulge of 2 kilometres might be developed in some regions unless prevented by isostatic adjustment.

FUSION-DEPTH CURVE.

Many factors determine at what temperatures rocks will liquefy at different levels in the earth. The composition of the rock is an important factor and of extreme importance is

the water content. Pressure is also a vital factor and all available experimental evidence forces the conclusion that, other things being equal, the temperature of fusion rises with depth. The depth-fusion curve is indicated in Figure 2 by the line F. Since the diagram is designed to express quantitative relations only between wide limits, the line F is drawn as a compromise between the curves which have been suggested by different authorities. The relations between the thermal gradients and the fusion curve, as indicated in Figure 2, suggest that conditions for magma formation are approached only locally in the sub-crust. There is the obvious suggestion, too, that at depths where the geoisotherms approach smoothness, temperatures are decidedly below those required to make magma at the different levels. It is indicated that under some regions, the strength[5] of rocks increases from the surface downwards to great depths and that under other regions, the strength increases at first, to weaken greatly at the level of possible magma formation (M in Figures 2 and 3) and, beyond that, to strengthen again into great but unknown depths.

LEVEL OF MAGMA FORMATION.[6]

Figure 2 shows within rather wide quantitative limits the region in which magma is most likely to be generated. Where the high thermal gradients meet the fusion curve, liquefaction is possible. This is indicated only for a single gradient and one which is by no means the highest. If higher gradients were chosen, the level of magma formation would rise above the depth of 55 or 60 kilometres, which is indicated by the relation of Curve 4 to the fusion curve. It should be emphasized that Figure 2 is meant to include only broad generalizations. There are infinite variations in the crust, both horizontal and vertical, and the same may be true of the shallower sub-crust. Only one stage in a cycle of change can be represented clearly in a single diagram. To initiate the cycle and to establish the conditions laid down in Figure 2, it is only necessary to assume that radioactive materials are considerably more

[5] Adams, F. D., and Bancroft, J. A., Internal Friction in Rocks, Jour. of Geol., vol. 25, p. 637, 1917.

[6] The discussion preceding and including this paragraph is in large measure a condensation of material already included in a thesis for the Master's Degree in the University of Manitoba, prepared by J. Spivack and, as well, in a joint paper by J. Spivack and the writer, presented in June, 1933, to the Pacific Science Congress, British Columbia.

concentrated under one region than under adjoining regions. It is conceivable that magma might form at many different levels between say 10 and 60 or at the outside 100 kilometres deep. Beneath each region, when its time comes, magma may form at one specific level.

GEOISOTHERMS.

Figure 3 represents a vertical section of a wide stretch of the earth's crust. The geothermal gradients of Figure 2 permit and facilitate the drawing of the geoisotherms in Figure 3. On the right and left sides of Figure 3 the various depth-temperatures provided by Curve 1, Figure 2,

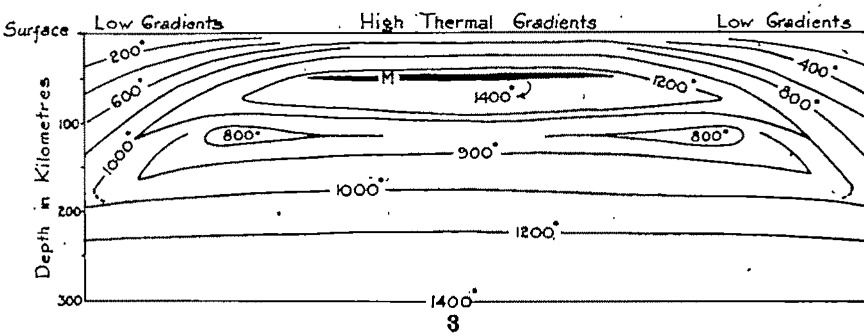

Fig. 3. Geoisotherms and the source of magma.

are indicated. Curve 4 similarly supplies the temperatures at various depths under the central regions. The same procedure with other gradients simplifies the drawing of the geoisotherms in Figure 3. It might be said that this figure applies to a special case and a particular environment. However, it simplifies the visualization of all cases. Later discussion will show that the figure discloses conditions which are both cause and effect in the cycle of crustal movement. With the dying out of conditions for magma growth in one region, the migration of magma introduces the same determining conditions to another region. Under a wide region the first-formed magma will have a sheet-like, or better, a thin-lenticular form. It will be underlain and overlain by rocks of great strength.

PRINCIPLE OF THE HYDRAULIC WEDGE.

Assuming that magma is formed before crustal movements set in, what is the effect of the generation of the magma? It

has the form of a circular or elliptical sheet, thinning to a wedge at the periphery. If the lenticular sheet of magma has the hydraulic pressure within it increased, in what direction will it move? Pirsson and Weed[7] have provided an excellent discussion of this problem and refer to the wedge and hydraulic-press effects in dealing with the problem of the origin of sheets and laccoliths. These intrusives are, however, phenomena of the outer crust. They are not at the site of magma formation but are introduced into bedded structures which favor the development of their particular forms. It is necessary, in the case of magma at depth, to assume an environment of solids which may be isotropic with respect to strength.

In applying a solid wedge to a homogeneous solid in an attempt to break the material, the wedge is pointed in a direction parallel to the plane along which it is desired that the solid should break. This point is of interest in its bearing on the solid flow of a wedge-shaped mass of rock. Let it be supposed that a lenticular cavity exists at the core of a sphere which is homogeneous and has uniform strength throughout. The cavity is filled with fluid which develops sufficient internal pressure to break the sphere. The sphere will break in the plane of the lens or wedge, even if it were compensated to offset any exceptional weakness in that plane, which might be induced by the existence of the lenticular cavity.

The magma of Figure 3 has the form of a wedge in the cross-section of its edge. With the passing of crystalline solid to glass there is a volume expansion. Room is made for expansion by a splitting of the surrounding solid in the plane of the hydraulic wedge. Moreover, this plane is the zone of greatest weakness in the crust: it is overlain and underlain by colder and stronger rocks.

THE MAGMATIC WEDGE AND SOLID FLOW.

In the case just discussed it was assumed that magma formed before there were any crustal movements. However, on looking at Figure 2, it is apparent that when Curve 3 approaches the fusion curve, the rock involved loses strength. At the same time distortion is growing in a region represented by D. It is conceivable that when 3 approaches F, the rock may be so weak, before magma forms, that isostasy will demand a

[7] Weed, W. H., and Pirsson, L. V., Geology and Mineral Resources of the Judith Mountains of Montana, U. S. Geol. Surv., Ann. Rep., 18th, Part III, p. 584, 1896-97.

correction of the distortion which is indicated by D in Figure 4. This distortion may correspond to a kilometre or more of thickness in the crustal bulge. As soon as solid flow takes place, the energy of the subsidence of a thick crust is largely converted into heat, derived from friction in a thin zone of solid flow. In this way there is introduced a new thermal disturbing agent. Incidentally this important source of heat for the generation of magma comes indirectly, in large measure at least, from the thermal energy of the interior of the earth. It follows that this internal heat may be lost by a method other than those of convection, magma migration, and simple conduction.

If solid flow is initiated before magma forms, for a time it will flow horizontally, with properties, depending on its strength, between those of a solid, and a hydraulic, wedge. It flows between stronger floor and roof just as the bottom layer of a continental ice-sheet, aided by higher temperatures, flows between the stronger carapace above and the rock-floor beneath.[8]

MIGRATION OF MAGMA.

It has been indicated already that there are two impelling forces which tend to make the magma spread laterally. These are the volume change which attends the formation of magma if solid flow changes to glassy flow and the other, the subsidence of the overlying crust. The wedge effect favors horizontal migration in either case. There is another possibility for volume expansion in the molecular changes of denser solids into those of lesser density, which might come about when temperature rises. It is only necessary to recall the effects on density of plutonic metamorphic agents, working at depths which are probably much shallower than those involved in this discussion.

The magmatic wedge of Figure 3 is now transferred to Figure 4 to permit the investigation of its possible migration. The original wedge S is driven by volume expansion and crustal subsidence in a horizontal direction. It will move chiefly in the direction of greatest weakness or of least resistance, which is chosen as to the left in the figure. Additional magma is generated and the edge of the wedge is say 100 kilometres farther to the left and the region under S′ is occupied.

[8] DeLury, J. S., Experiments with Model Glaciers, Jour. of Geol., vol. 34, pp. 266-74, 1926.

The crustal bulge, originally D, is extended to D′, because S′, by its invasion of a new area, creates conditions beneath, which lead to further thermal distortion. The distortion keeps on developing under new regions; and, under the old, until a balance is established between distortion, subsidence, and migration. The driving force behind the sheet grows, as it may be presumed to grow under an ice-sheet, as it proceeds from centre to periphery. It might be said that when magma is formed the creation of a crustal bulge is automatically stopped. This is not necessarily the case and even if it were (on account of the strength of the earth's crust), the energy of the distortion would still be available for sheet-flow.

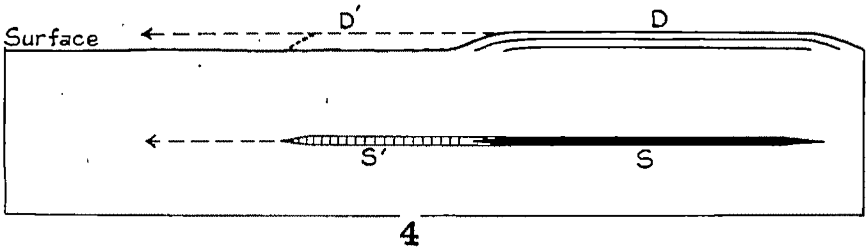

Fig. 4. Migration of magma and thermal distortion.

The sheet-flow grows horizontally and as it grows it further widens the possibility for its growth. It suggests, in this way, a self-perpetuating mechanism, slow in the generation of its energy, slow in its movements, but ever active. The colossal energy involved in the subsidence of a thick crust of continental dimensions through a distance of a few hundred feet has already been discussed by the writer. Energy in such quantity, with a proper mechanism through which it might operate, is competent to fold mountains, to elevate a plateau, and to supply magma for the cores of mountain-chains or, in the course of time, to build continents. The concern is now, however, with the basic theory which must be developed before it is subjected to quantitative tests or to the actual interpretation of the events of geological history.

CONCLUSIONS.

In the horizontal variations of the crust lies the key for the solution of the problem of crustal mechanics. The most specific geophysical evidence comes from a study of geothermal

gradients and from the evidence of the variation of these in the past, which is contributed in some measure by the study of igneous intrusion and extrusion throughout the history of the crust. The same mechanism which the writer has claimed is necessitated by the demands of crustal structures, has been arrived at by an appeal to the safest geophysical evidence while keeping in mind cognate geological data. It is not difficult to see the possibilities of auto-traction which would logically be effected by a horizontally migrating sheet-flow with the energy of the subsidence of an enormous area behind.

It is not intended at this time to enlarge on the bearing of the conclusions from this paper on other theories that are now to the fore and on the major problems of the crust. A further contribution is in course of preparation.[9] However, some general and obvious inferences might be permitted at this time. It follows, if the crustal mechanism and conditions at depth are of the nature indicated in the present paper, that:—

Continental drift, in its broader meaning, is impossible from the evidence that, except locally, strength of rocks increases with depth.

For the same reason, universal convection currents are now impossible and their possibilities have probably been extinct for the greater part of geological time.

Isostatic adjustment is not effected through a deep and thick substratum (the asthenosphere), but through comparatively shallow and locally developed levels of sheet-flow.

Magmas have been locally formed and locally extruded throughout geological time. The sources of magma are not huge vertically disposed magma-chambers, which rise vertically and expand by embodying the overlying crust. Assimilation, in its broadest aspect, would appear to be the controlling factor in the development of diverse rock types, though some aspects of differentiation cannot be ignored.

[9] DeLury, J. S., The Significance of Horizontal Variations in the Crust, offered at the Annual Meeting, Royal Society of Canada, May, 1933.

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PRE-CAMBRIAN GEOLOGY OF THE NEMO DISTRICT, BLACK HILLS, SOUTH DAKOTA.

J. J. RUNNER.

INTRODUCTION.

It is the purpose of this paper to discuss the stratigraphic and structural relations of certain formations believed to lie at the base of the pre-Cambrian of the northern Black Hills of South Dakota and to present evidence of an unconformity that separates the formations into two divisions of the rank of systems. Other pre-Cambrian formations lying stratigraphically above the two older systems are grouped into a third. The contact of the youngest system with the older two is interpreted as most probably a fault contact although there is considerable evidence that it may be an unconformable one.

PREVIOUS WORK IN THE DISTRICT.

The most important papers bearing on the subject are by Newton,[1] Crosby,[2] Van Hise,[3] Paige,[4] and Runner.[5]

Summarizing the previous work, we find the conglomerates, quartzites, and iron formations of the Nemo district described by Newton, Crosby, and Van Hise, no one of whom suggests an unconformity between any formations. An unconformity between schist series and slate series, urged by Newton and Crosby and opposed by Van Hise, is not the one discussed in this paper and apparently has no relationship to it.

Paige mapped the major lithologic units of the Black Hills pre-Cambrian, recognized and described many major structural features and suggested similarities in stratigraphy in the Lead, Nemo, Rochford, and Upper Spring Creek areas. In the Nemo district he interpreted the structure as that of an anticline faulted on its western flank. In the same region, he mapped conglomerate, quartzite, arkosic grits, limestone,

[1] Newton, Henry, Geology of the Black Hills of Dakota, U. S. Geog. & Geol. Survey of the Rocky Mountain Region, 1880.

[2] Crosby, W. O., Geology of the Black Hills of Dakota, Bost. Soc. Nat. Hist. Proc., Vol. XXIII, pp. 488-517, 1888.

[3] Van Hise, C. R., The Pre-Cambrian Rocks of the Black Hills, Bull. Geol. Soc. Amer., Vol. 1, pp. 203-245.

[4] Darton, N. H., and Paige, Sidney, Central Black Hills Folio, South Dakota, U. S. Geol. Survey, Geol. Atlas Folio 219, 1925.

[5] Runner, J. J., Evidences of an Unconformity within the Pre-Cambrian of the Black Hills of South Dakota, Bull. Geol. Soc. Amer., Vol. 32, pp. 37-38, 1921.

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quartz-hematite beds, quartz-pyrite replacement veins and amphibolite. He interpreted the conglomerates as the oldest rocks in the Black Hills pre-Cambrian.

Although Paige's was the first published geologic map of the Nemo district (1925) the author had in 1920 read a paper before the Geological Society of America, setting forth the same interpretation of the geology as presented in this paper, illustrated with a map and structure sections identical with those of Fig. 1. An abstract of the paper was published at that time.[6]

STRATIGRAPHY.

Heretofore, no separation of the formations of the Nemo district into systems has been made, no formational or systemic names have been applied to them, and no definite correlations have been made with pre-Cambrian formations of other portions of the Black Hills region.

The writer proposes the names Nemo system and Estes system for the assemblages described below. These systems have been subdivided on a lithologic basis into members rather than into formations because of the very limited areal extent of these members. No proper names have been applied to the various members.

For the third and youngest system, separated from the older two by faults or unconformity, the name Lead system is proposed. The formations of the Lead system are believed to be traceable with interruptions to the Lead district where they were first described by Paige.[7] Later these formations were described in more detail and formational names given them by Hosted and Wright,[8] and still later again described by Paige,[9] and by Paige, Hosted and Wright.[10] Recently McLaughlin[11] and Gustafson[12] have added more details.

[6] Runner, J. J., op. cit.

[7] Paige, Sidney, Pre-Cambrian Structure of the Northern Black Hills, South Dakota, and its Bearing on the Origin of the Homestake Ore Body, Bull. Geol. Soc. Amer., Vol. **24**, pp. 293-300, 1913.

[8] Hosted, J. O., and Wright, L. B., Geology of the Homestake Ore Bodies and the Lead Area of South Dakota, Eng. & Min. Journal Press, Vol. **115**, pp. 793-799 and 836-843, 1923.

[9] Paige, Sidney, The Geology of the Homestake Mine, Econ. Geol., Vol. **18**, pp. 205-237, 1923.

[10] Paige, Sidney, Geology of the Region Around Lead, South Dakota, and its Bearing on the Homestake Ore Body, U. S. Geol. Survey Bull. **765**, 1924.

[11] McLaughlin, Donald H., The Homestake Enterprise—Ore Genesis and Structure, Eng. & Min. Journal, Vol. **132**, pp. 324-329, 1931.

[12] Gustafson, J. K., Metamorphism and Hydrothermal Alteration of the Homestake Gold-Bearing Formation, Econ. Geol., Vol. **28**, pp. 123-163, 1933.

The Nemo System.

By reference to the accompanying geological map (Fig. 1), it will be seen that the oldest rocks in the Nemo district, comprising the Nemo system, are to be found near the central

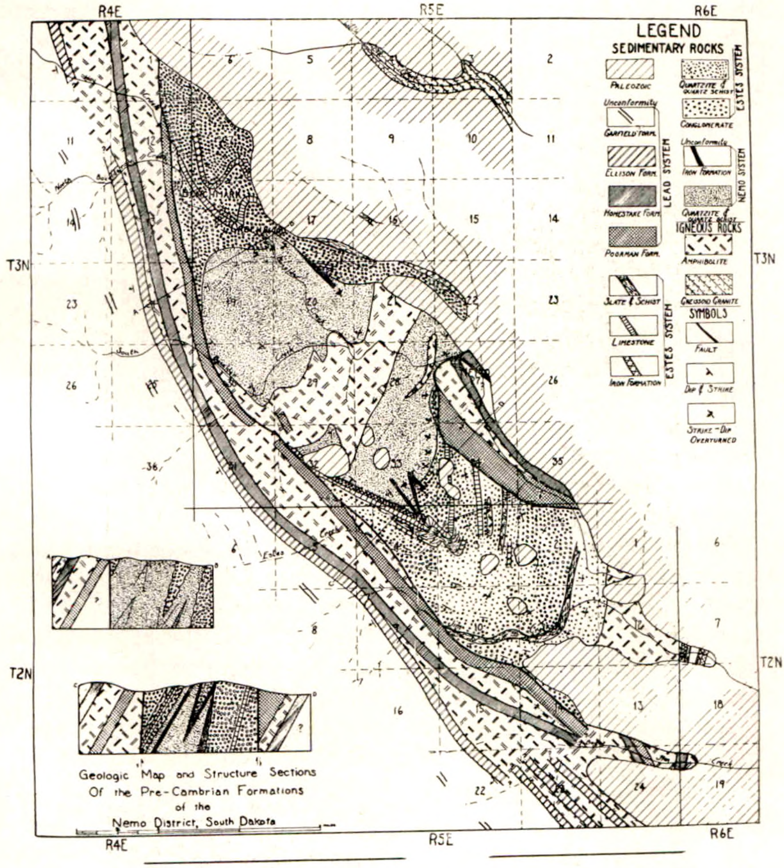

Fig. 1. Geologic Map and Structure Sections of the Pre-Cambrian Formations of the Nemo District, South Dakota.

part of the area lying west of the small town of Nemo in Section 27. Altogether they cover an area of approximately 5 square miles. They have been broken apart and separated by an intrusive mass of amphibolite into a northern and a southern portion.

The Nemo system includes two classes of sediments, arenaceous beds comprising quartzite, arkosic and graywacke

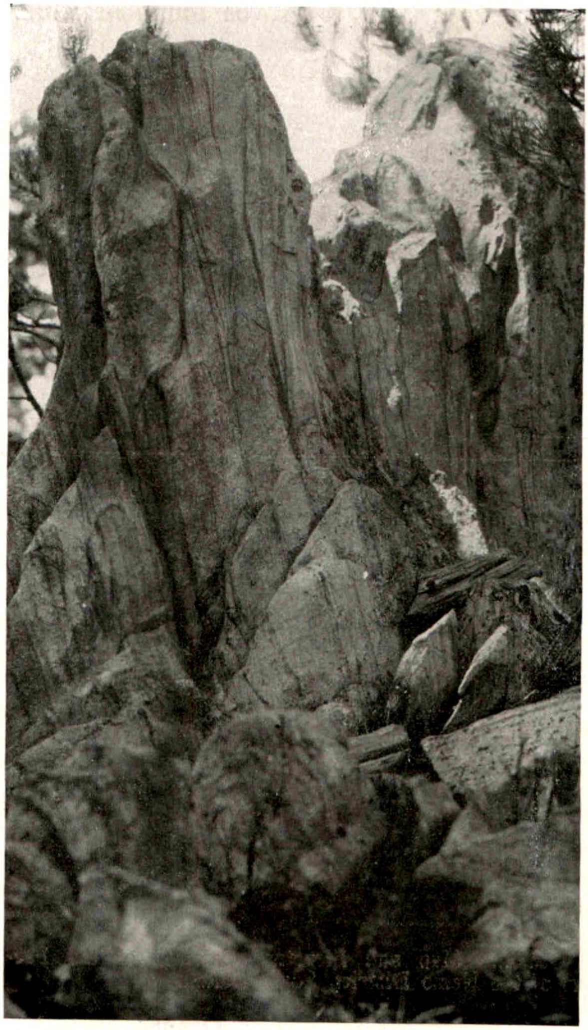

Fig. 2. Crossbedded Quartzite of Nemo System.

schists; and banded iron formations. The former are the older, on the whole, and make up the greater portion of the system.

As a rule the Nemo quartzites are distinctly granular, and although some portions exhibit well-defined bedding planes, in most of the rock bedding planes are obscure. A few scattered grains of milky quartz as large as 1 cm. in diameter were the coarsest fragments found. Some portions are dense and break with a smooth fracture resembling chert. In the southern part of Sec. 33 these rocks contain appreciable quantities of magnetite distributed along the true and false bedding planes and serve to mark the latter clearly (Fig. 2).

The schistose facies of the Nemo system have been derived by recrystallization, which has converted quartzose argillites, arkoses and graywackes into micaceous and chloritic, quartz schists.

The iron formations of the Nemo system consist in the main of alternate bands of fine white crystalline quartz with black micaceous hematite and magnetite. The percentage of iron generally varies from 10 to 20, but in some cases it is as high as 30 per cent. The bands are greatly contorted by drag folding and in places are brecciated and faulted.

Traced along the strike some beds become more and more siliceous and finally grade into quartzite. In other places by loss of iron the formation grades into a banded chloritic, quartz, hematite schist.

As to the origin of the iron formations, no definite conclusions have been arrived at. The fact that they conform closely to the structure of the quartzite and grade into it indicates that they are of sedimentary origin. They do not appear to be associated in origin with any igneous rock exposed in the area.

Data on the aggregate thickness of beds exposed comprising the Nemo system are very uncertain because of difficulty of determining the number of repetitions by folding. It appears unlikely that the thickness is less than 5000 feet or more than 12,000 feet.

The Estes System.

Reference to the accompanying geological map (Fig. 1) will show the Nemo system surrounded by the Estes system except where the contact is obscured by the Paleozoic overlap or where the Nemo system is faulted against the Lead system. As indicated in the legend to this map, the system has been subdivided on a lithological basis into conglomerates, quartzites and quartz schists, iron formations, limestones, and slates.

Fig. 3. Coarse Conglomerate at base of Estes Series.

Each type of sediment has been found to grade laterally along the strike and upward and downward stratigraphically into various other lithologic units of the system.

The name Estes was taken from the creek of that name along which the beds are prominently exposed.

Conglomerates.—The conglomerates are perhaps the most interesting rocks belonging to the Estes system because of their tremendous thickness, the large size of many of the bowlders contained, and because of the fact that they are interbedded with limestones and iron formations. The conglomerates containing largest bowlders showing least rounding are to be found at the base of the system. Such a conglomerate occurs in the eastern part of Sec. 33, T. 3 N., R. 5 E., at the contact with Nemo quartzite. (Figs. 3, 4.) Here bowlders of crossbedded gray quartzite, containing streaks of magnetite sand along true and false bedding planes, have been observed that measured eight feet by three feet as exposed at the surface. In the conglomerates at the same place are large bowlders of banded iron formation containing drag folds, brecciated and faulted structures that were produced before the rock was eroded to form the conglomerate. In general the iron formation bowlders of the conglomerate are more siliceous than are many parts of the iron formation itself, doubtless because the more siliceous parts of the latter were more resistant.

Other kinds of bowlders commonly found near the base of the system, in masses of considerable size, are of white milky quartz, light gray, dark gray, and brown quartzite. All of these kinds of rock are known to occur in the beds of the Nemo system within a few hundred feet of the contact of the two systems.

The matrix of the conglomerate is generally siliceous where the bowlders and pebbles are of quartzite, and a chloritic schistose one near beds of limestone and iron formation. Like the bowlders, the matrix of the conglomerate resembles the local facies of the Nemo system.

Rock flowage caused the development of plane cleavage in the matrix and the shaping of the bowlders and pebbles into triaxial ellipsoids. (Fig. 4.) It was observed that the maximum and intermediate dimensional axes lie in the plane of flow cleavage parallel to the axial plane of the folds and that the long axis is parallel to the pitch of the folds.

Fig. 4. Elongated Bowlders of Estes Conglomerate.

The possibility that some of the conglomerate might be glacial was carefully tested but no evidence was found of such an origin.

The coarse angular bowlders found near the base of the system are of very local origin and may well represent talus

from a cliff, an alluvial fan, or possibly a delta deposit near an area of highlands. The great thickness of the deposit is in keeping with such an interpretation.

A conservative estimate of the total thickness of beds containing bowlders and pebbles of a minimum diameter of 1 cm. would be greater than 4000 feet and perhaps less than 5000 feet.

Quartzites and quartzose schists.—The greater part of the beds comprising the Estes system are the metamorphosed equivalents of quartzose and arkosic sands. They occur interbedded with and grade into the conglomerates both along and across the strike. Many of them strongly resemble the quartzites and quartzose schists of the Nemo system. They, however, show a greater total range of composition and texture and are more variable within short distances. With an increase in the proper constituent, they grade into iron formation, limestone, green schists or slates.

Iron formations.—The beds within the Estes system designated as iron formations represent three principal types: ferruginous conglomerate, ferruginous quartzite, and ferruginous and siliceous slate. All are banded rocks, thin seams of specular hematite and magnetite alternating with silica or siliceous slate. The iron content is variable, ranging from ten per cent to over fifty per cent, and averaging perhaps between fifteen per cent and twenty per cent. They occupy no single stratigraphic horizon and have a very limited lateral extent. They are regarded merely as facies of the conglomerates, quartzites, or slates, respectively, which contain an abnormal amount of iron. In general they are more numerous and better developed near the base of the Estes system and near the iron formations of the Nemo system.

Figure 5 from the west center of Sec. 7, T. 3 N., R. 5 E. shows iron formation grading upward (toward the right) into conglomerate that contains numerous elongated bowlders of an older iron formation and quartzite. Sufficient variety among the quartzite bowlders in this rock eliminates all possibility that they may be merely thick lenses of chert or deformed veins of secondary quartz. In places the gradation is from iron formation to a conglomerate with a gray or brown, granular, sandy matrix; in others into a conglomerate with a green, schistose matrix.

The occurrence in the conglomerates of pebbles and bowlders of precisely similar composition and structure to the

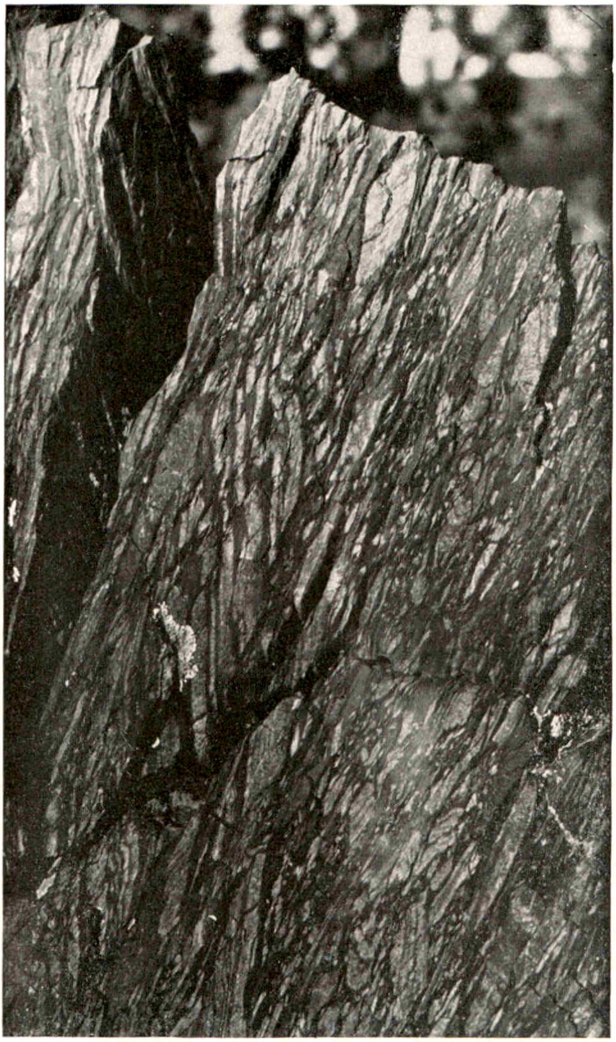

Fig. 5. Banded iron formation on left grading into ferruginous conglomerate on right. Latter contains bowlders of quartzite and of older iron formation from Sec. 7, 3 N., R. 5 E.

iron formation of the Nemo system and the gradation of the quartzite conglomerates near the Nemo iron formations into portions containing a greater percentage of iron formation fragments and finally into banded iron formation points

strongly to the view that the iron formations of the Estes system have been derived from the iron formations of the Nemo system by erosion and redeposition.

That the iron of the iron formations was not derived from any igneous rock within the region seems clear. All igneous rocks now exposed are intrusive and younger than the beds containing the iron formations. That they are not epigenetic is evident from their clastic nature and indirectly from the fact that there seems to be no connection in distribution between iron formations and igneous rock.

The banding may be in part of sedimentary origin but the occurrence in Sec. 4, 2 N., 5 E., of bands of hematite and quartz diagonal to the strike of the beds and parallel to the plane cleavage is evidence that some of it was developed by metamorphic processes. The banding is best developed in the finer grained clastic iron formations and in those parts in which the iron is in greatest abundance.

Limestones.—Two beds now containing at the surface perhaps less than 10% of carbonate of lime and magnesia and 90% or more of silica have been mapped as limestone because of the probability of their having been once siliceous, cherty limestones. They lie near the base of the Estes system and possibly the meta-derivatives of such rocks occur at higher horizons, as noted below under the discussion of the green schists.

Both beds present rather uncommon features when compared with other limestones. In places they are interbedded with conglomerate and quartzite into which they pass by changes in composition both along and across the strike. Some portions are buff-colored, fine-grained, carbonate rocks with numerous thin seams of crystalline quartz that weather out into little ridges with depressed pits of carbonate material between. Other portions are light gray, granular, siliceous rocks appearing more like sandstone with a calcareous cement. Still others are made up largely of lens-shaped masses of white silica set in a light colored granular matrix containing some calcareous material, the whole resembling a sheared conglomerate. A careful examination of these pseudo-conglomerates revealed the fact that the siliceous lenses are made up of crystalline quartz of very uniform character, whereas the true conglomerates both above and below contain a rather wide assortment of bowlders of vein quartz, iron formation, and various quartzites. They apparently have been derived from

original limestones containing numerous nodules and lenses of chert whose silica was first partly dissolved and redistributed, replacing in part the calcareous matrix. The whole was subsequently sheared and the siliceous portions were recrystallized into fine granular aggregates.

In the southeastern portion of Sec. 32, T. 3 N., R. 5 E. the limestones present other interesting features. Here the limestone beds are thin and, as usual, siliceous. In places they have been brecciated and the fragments sheared and the interstices filled with calcite or dolomite so that they resemble conglomerate with a calcareous matrix. Places are to be found in the area where the limestones have been metamorphosed into green chloritic schists still containing high percentages of carbonates.

Slates and Green Schists.—Slates derived from argillaceous sediments and green schists derived from the more ferruginous, calcareous or dolomitic argillites occur at several places within the Estes system. Like the iron formations and limestones, they are not traceable for long distances and grade into other rocks. They are therefore to be regarded merely as local facies of the sedimentary series.

Thickness of the Estes System.—The aggregate thickness of the beds of the Estes system exposed in the northern part of T. 2 N., R. 5 E. doubtless exceeds 15,000 feet and the top is not exposed. Approximately one-third of this is conglomerate and of the remaining two-thirds much the greater part is quartzite and quartz schist.

The Lead System.

Lying east and northeast of, and truncating the beds of the Nemo and Estes systems in Sec. 27, 34 and 35, T. 3 N., R. 5 E. and in a long narrow belt bordering the same on the west and extending from the southeastern to the northwestern portions of the map of Fig. 1, are formations believed to correlate with formations of the Lead district. These formations have been traced beyond the borders of this map northward to a point 2 miles northeast of Roubaix, where they pass under the Paleozoic overlap or under sheets of Tertiary igneous rocks. They are believed to continue to a point northeast of Deadwood and merge with the formations of the Lead district which extends northeastward from Lead to upper City Creek, Deadwood.

The general sequence in both Nemo and Lead districts is limestones and calcareous slates—Poorman formation; siliceous and ferruginous carbonate beds—Homestake formation in parts; slates and quartzites—Ellison formation in part; garnetiferous mica schists—Northwestern formation; and pyritiferous quartz layers termed the Garfield formation. In both districts long sill-like bodies of intrusive igneous amphibolite occur but these have a far greater development in the Nemo than in the Lead area. For these sedimentary formations and others lying conformably below and above, whose limits have not yet been determined, the name Lead system is here proposed. The Lead district where the formations here described are much better known and have been more fully described should be taken as the type area for the Lead system.[13, 14, 15, 16, 17] It is not to be understood that formations of the Nemo district have exactly the same stratigraphic significances in the Lead district inasmuch as their upper and lower limits have not been precisely determined in the former district.

Poorman Formation.—In the Nemo district the Poorman formation includes four kinds of sedimentary rock, a quartzite below overlain by thick beds of siliceous limestone interbedded with green schists and black slates above. The quartzite of the Poorman formation is a fine-grained dense pink to black quartzite of quite uniform character. Its thickness averages perhaps 200 feet. On the surface the limestone of the Poorman is chocolate brown to buff in color, rarely gray or white, in places contains lenses of chert and is generally cut by thin seams of crystalline quartz running in various directions, giving rise by weathering to a very rough surface dominated by small sharp ridges. In places it has been partially replaced by streaks of iron oxide. Specimens taken from prospect holes were found to consist dominantly of alternate light and dark bands of well-crystallized carbonates with little silica or other impurity except along shearing planes where micas and chlorite had developed. In thickness the limestones of the Poorman range from no more than 200 feet to well

[13] Darton, N. H., and Paige, Sidney, Central Black Hills Folio South Dakota, U. S. Geol. Survey Geol. Atlas Folio 219, 1925.

[14] Paige, Sidney, Geology of the Region Around Lead, South Dakota, and its Bearing on the Homestake Ore Body, U. S. Geol. Survey Bull. 765.

[15] Hosted, J. O., and Wright, L. B., op. cit.

[16] McLaughlin, Donald H., op. cit.

[17] Gustafson, J. K., op. cit.

over 800 feet. Where thickest there are two beds separated by green schists.

Homestake Formation.—In Secs. 27, 34 and 35 the Homestake formation varies from a banded quartz-hematite rock containing in places as high as 50% Fe_2O_3 and closely resembling the iron formations of the Nemo and Estes systems, to a very siliceous and ferruginous black slate. In Secs. 14 and 15 it is similar to the above while farther northwest in Secs. 5 and 30 it contains siliceous and ferruginous dolomite layers interbedded with ferruginous slate. In Sec. 1 and in Sec. 13 it resembles banded black ferruginous chert. Where long exposed to weathering the surfaces are much pitted, presumably due to the solution of carbonates. The ferruginous and siliceous beds appear to be facies of the upper part of a formation largely slate containing numerous layers of dolomite. Near Roubaix on Elk Creek the formation contains crystals of fibrous amphibole in bands with lenses of granular quartz and is drag-folded on a minute scale greatly resembling the same formation at Lead. In the region between Hay Creek and Elk Creek and at the latter place it has been prospected for gold. Some prospecting for gold and iron has been done in the Nemo region.

The origin of iron and silica in these beds is a very interesting and important problem. From the intimate association of such beds with amphibolites in the Nemo, Roubaix, Rochford regions and to a lesser extent in the Lead region and from the association of other ferruginous sediments with similar amphibolites west of Hill City and in the region between Bogus Jim Creek and Keystone it is highly suggestive that much of the iron and silica in the sediments was derived from the amphibolites.

Ellison Formation.—The Ellison formation may be regarded more properly as a quartzite formation consisting of several members interbedded with slate. The exact number of beds varies from place to place. In places four or five beds of quartzite varying in thickness from 20 to 200 feet occur while in others there appears to be only one bed with a thickness varying from 400 to 600 feet. Topographically the quartzites form long ridges and knobs rising to elevations of more than 5700 feet. Through the quartzites, the streams have cut narrow, steep-walled valleys.

The quartzites are quite uniform in composition and are composed of black, gray, or reddish, fine-grained massive

layers. Normally they break into huge smooth-faced rectangular blocks that form thick talus piles at the base of the steep walls of the formation. Numerous veins of white quartz cut the rock, for the most part parallel to the bedding. Although much less prominent topographically the greater part of the Ellison in the Nemo district is dark clay slate often pyritiferous.

Northwestern Formation.—Lying above the slates and quartzites of the Ellison with apparent conformity are several thousand feet of micaceous schists and phyllites that in places are highly ferruginous. Thin quartzites or quartzitic veins occur frequently.

Garfield Formation.—In the Lead district pyritized graphitic slates associated with ferruginous quartzite occur that have been called the Garfield formation. Similar beds are found in the Nemo region at several horizons above and even below the Ellison, and others of the same general character have a widespread development in many places in the pre-Cambrian of the Black Hills. These beds are everywhere closely associated with amphibolite. It is very doubtful if the Garfield even of the Lead district should be regarded as a true sedimentary formation.

The total thickness of the Lead system in the Nemo district was not determined for the reason that its upper limits are not known. However, it is certainly several and perhaps many thousands of feet in thickness.

IGNEOUS ROCKS.

Gneissoid Granite.

Gneissoid granite occupies the valley of Little Elk Creek in Secs. 3 and 4, T. 3 N., R. 5 E. In a few places the rock is massive but is generally well banded with mica flakes in parallel position occupying well-defined layers between quartz feldspar bands. The foliation is partially due to lit-par-lit injection and partially to recrystallization under differential pressure subsequent to its first crystallization.

In thin section the rock is found to be composed of microcline, orthoclase, and albite feldspar, 60%; quartz 25%; biotite and muscovite together 15%; with subordinate amount of apatite, tourmaline, zircon, and pyrite. In places much epidote has developed in the feldspars. Small aplite dikes frequently cut the main mass. These contain alkali feldspar 75%, and

quartz 25%, with occasionally a little tourmaline and muscovite. The grain of the aplites is very fine, almost felsitic. Occasionally small veins of quartz 90%, tourmaline 10%, with a little apatite, muscovite, rutile and pyrite cut the rock. The coarser, granitic facies show the effects of much granulation and slicing of mineral constituents, while the aplite and quartz-tourmaline veins have been intruded along and across the structural planes of the granite and show little of such effects. The granite is clearly intrusive into the pre-Cambrian sediments but its relation to the amphibolites described below is not so clear. The border zone is dominated by numerous small dikes extending into the sedimentary schists. The form of the main intrusion is unknown as its outcrop is very limited in extent.

Amphibolite.

Of the area of pre-Cambrian rocks shown in Fig. 1, covering approximately 27 square miles, more than one-third is occupied by various facies of basic igneous intrusive rocks that have been designated on the map amphibolite. No attempt was made to make exhaustive petrographic studies of these rocks, and only a few were sectioned and examined under the microscope.

Generally, the amphibolites are dark green in color and rather fine-grained, the individual constituents rarely exceeding one-fourth cm. in area of cross section. For the most part, they are schistose, but less so than are the sediments. The degree of schistosity is greater in the smaller masses and near the margins of the larger ones. In many places they are cut by veins of calcite and dolomite, suggesting that some may be metamorphosed calcareous sediments.

In the thin sections examined approximately 80% of the rock was hornblende, the larger portion of the remainder consisting of idiomorphic outlines of plagioclase replaced by quartz, epidote and zoisite, and to some extent by the amphibole. Small amounts of magnetite and pyrite also occur. The chemical composition is sufficiently basic to make it highly probable that the original rock may have been an intrusive diabase or gabbro.

Within the Nemo system the amphibolites occur chiefly in a large irregular mass with cross-cutting relations to the sediments. In the Lead system they lie in long narrow belts parallel to the strike in the form of nearly vertical sills.

Only an insignificant amount of this rock was found intrusive into the Estes system.

The igneous amphibolites appear to transect the older structures of the Nemo system. If this be true, they are younger than the deformation that produced those structures. They have been intruded in the form of vertical sills into the Lead system and possess the same foliation as the beds of that system. It would appear from this that they are either older than or contemporaneous with the deformation of the Lead system.

GEOLOGIC STRUCTURE.

Folds.

The major fold in the region is a doubly pitching isoclinal anticline overturned toward the northeast, the axial plane of which dips about 75° southwest and the axial lines pitch at angles of from 60° to in a few places more than 90°. Paige interpreted the structure as a southward pitching anticline.[18]

The upper side of the beds of Nemo quartzite in the southeastern part of Sec. 33 is toward the southeast as determined from cross-bedding. The same data were obtained in the conglomerates of the Estes system in Sec. 34. The gradation from coarse to fine conglomerate likewise is toward the southeast. Near Greenwood in Sec. 18 at the northern end of the structure similar data indicate the top of beds toward the northeast. These data show that the base of the conglomerate is at its contact with the Nemo system. If this contact extends as indicated on the map, Fig. 1, the structure can only be that of a doubly plunging anticline. Smaller folds superimposed on the major anticline are apparent from the curving of the strike of beds of limestone, iron formation, and slate in the Estes system near the contact and elsewhere. These latter folds are shown in the structure sections of Fig. 1.

The folding above described affected Nemo and Estes systems, probably also the Lead system, similarly. That the Nemo system had been previously folded is evident in several places where the basal conglomerate of the Estes system truncates those folds; a good example is in the S. E. ¼ of Sec. 33. The folds in beds of the Nemo system are more accentuated but the axial planes are generally parallel with those of the Estes system.

[18] Darton, N. H., and Paige, Sidney, op. cit.

Faults.

What appears to be two major faults brings the beds of the Lead system into contact with and truncate the beds of both Nemo and Estes systems. The fault in the western part of the area is approximately parallel with the strike of the Poorman formation but the fault southeast of Nemo appears to truncate beds of the Lead system as well as the older beds. The two faults are on either flank of the main anticlinal structure and apparently the central portion has been raised by both faulting and folding. The intrusion of the amphibolite mass that occupies the center of the area in Secs. 21, 28, and 29 may very likely have raised the central area into a domical fold and caused the upfaulting of the same mass.

THE NEMO-ESTES UNCONFORMITY.

The principal structural feature is that of an elongated dome. The oldest beds are necessarily in the interior of the dome. Surrounding the central area of apparently conformable beds of quartzite and arkosic and graywacke schists and iron formations on all sides, except where faults, igneous rocks or Paleozoic overlaps occur, is a belt of coarse conglomerate. This conglomerate clearly truncates the beds of the central area and contains large bowlders of the same rocks as are to be found in the formation of that area near the contact of the two. The crowns of anticlines have been eroded and conglomerates deposited across the eroded surfaces. Folds in the older rocks have been repeated in the younger ones during subsequent deformation but are less accentuated in the latter.

Bowlders of well-cemented quartzite set in a chloritic schistose matrix, bowlders of drag-folded, faulted and brecciated iron formation and of vein quartz in the conglomerate indicate that the underlying rocks had been buried sufficiently deep for anamorphic processes of considerable importance to take place. In view of the facts it seems justifiable to regard the time interval intervening to be as great as that separating most geologic periods and hence the rock units have been designated as systems. The thicknesses of rock, too, are comparable to that of many systems. It was thought best to give local names to them because of the very limited known areal distribution. When they have been correlated with recognized equivalent units of some other area, the names may be dropped, but until then they serve a useful purpose.

POSSIBLE UNCONFORMITY BELOW LEAD SYSTEM.

The field relations of the Lead system to the Nemo and Estes systems may be explained by the presence of a second major unconformity. The distribution and structural relations of the amphibolites also suggest such a possibility. As pointed out above, where the igneous amphibolites have intruded the formations of the Nemo system they have cross-cutting relations. In the Lead system they have spread laterally in the form of sills. Similar relationships to formations believed to be the stratigraphic equivalent of the Lead system occur in the Rochford, Custer, Keystone, and Upper Spring Creek districts and to a lesser extent in the Lead district. Even should the relations of the Lead system to the two older ones be that of a fault in the Nemo district, it seems justifiable to regard it as a separate system because of the great thicknesses of rocks lying below the limestones of the Poorman formation and above the Estes system in other districts. Limestones and amphibolites occur both east and west of Custer in the southern hills and between these rocks and thick beds of quartzite, presumably of the Estes system, are several hundred feet of mica schists. The relation of the schists and quartzites in that region is somewhat obscure but strongly suggests a great fault or unconformity.

CORRELATION OF THE BLACK HILLS PRE-CAMBRIAN.

In an isolated province such as the Black Hills so far from other carefully classified pre-Cambrian there is little upon which to base correlation. From what the writer has seen of and read about the pre-Cambrian of the Lake Superior district or the Canadian shield the rocks of the Black Hills may correlate with any two or three systems not separated by unconformities as great as those that separate the Keewatin and Huronian. They might, for example, be Sudburian, Huronian, and Animikean, or perhaps Lower and Upper Huronian and Keweenawan. The pre-Cambrian section in the Medicine Bow mountains of Wyoming described by Blackwelder[19] has a similar lithologic sequence but differs from the Black Hills section in having no apparent unconformities. It is instructive to place the two side by side for comparison.

[19] Blackwelder, Eliot, Pre-Cambrian Geology of the Medicine Bow Mts., Bull. Geol. Soc. Amer., Vol. 37, pp. 615-658, 1926.

MEDICINE BOW MOUNTAINS.		BLACK HILLS.	
Acidic intrusives Basic intrusives Relative ages uncertain		Granite Amphibolites—basic intrusives	
French slate	Black pyritic slate; some quartzite	Garfield formation Northwestern formation Ellison formation	Ferruginous quartzite mica schists and phyllite Slate and quartzite
Towner greenstone Ranger marble Anderson phyllite Nash marble	Green schists Limestone Phyllite and dolomite Limestone	Homestake formation Poorman formation	Ferruginous carbonate rocks, calcareous slate and limestone
		Possible Unconformity.	
Sugarloaf quartzite Lookout schist Medicine Peak quartzite Heart graywacke	Thick clastic sediments	Estes system	Very thick quartzite, slate iron formation and arkosic grits
Headquarters formation	Schistose tillite, quartzite and dolomite		Conglomerate, quartzite, limestone, and slate
		Unconformity.	
Deep Lake quartzite	Thick quartzite	Nemo system	Quartzites Some iron formation

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THE AGENCY OF ALGAE IN THE DEPOSITION OF TRAVERTINE AND SILICA FROM THERMAL WATERS.[1]

E. T. ALLEN.

INTRODUCTION.

What part do micro-organisms play in the formation of hot-spring deposits? That is a question often raised and discussed during the years when the writer was engaged in the study of thermal springs in the Yellowstone National Park. Many chemists and geologists, as well as biologists, have shown an interest in the problem, but the opinions they have expressed differ widely, some supporting the paramount influence of the organisms, others maintaining the dominance of purely inorganic agencies.

The purpose of the present article is to consider the matter in its quantitative aspects; it seeks to determine whether the activities of the plant life, inhabiting these hot-spring waters, are sufficient in degree and extent to class them as a factor of geological importance. "Importance" is used of course in a relative sense; in its broader meaning, the total volume of all the hot-spring deposits of the globe is insignificant. The two types of deposit here considered, travertine and silica, call for separate discussion, as the conditions of formation are not the same for both.

PRECIPITATION OF TRAVERTINE FROM THERMAL WATERS.

The precipitation of calcium carbonate from hot-spring waters is entirely similar in principle to its formation from sea water,[2] a subject to which so much attention has been given of late years, especially by the Scripps Institution of Oceanography, but deposition in springs is naturally much easier to approach. No attempt is here made to contribute either to the theoretical side of the question, as it applies to chemical equilibrium in the complex waters, or to the character of the physi-

[1] A briefer discussion of this subject depending on the same observations will be found in a forthcoming book: "Hot springs of the Yellowstone National Park," by E. T. Allen and Arthur L. Day; Microscopic examinations by H. E. Merwin.

[2] Johnston and Williamson, J. Geol., 24, 729, 1916.

Gee, Haldane, J. Sed. Petrol., 2, 162, 1932; Carnegie Inst. Washington, Publ. No. *435*, 67 and 83, 1932.

Gee, Moberg, Greenberg and Revelle, Bull. Scripps Inst., *3*, No. 7, 145, 1932; No. 8, 191, 1932.

ological function which living organisms may perform in the mineral springs. These important matters must be left to those especially equipped for the task. The investigations of the writer have been pursued with an eye to the volcanological significance of the various phenomena, but at the same time observations and tests have been made, which are believed to throw additional light on the problem of deposition. All field observations relating to calcium carbonate were carried out at the Mammoth Hot Springs, a group whose easy accessibility enabled us, during the seven summers of our stay in the Park, to become quite familiar with its essential features. The active area, not more than half a square mile in expanse, is characterized by a succession of travertine terraces of unknown thickness, extending up a mountain slope for a thousand feet, dotted with springs and pools of various sizes, the majority of which range in temperature from 60° to nearly 75°C. Sinter deposits old and new have been estimated to cover an area not far from two square miles.[3] A feature to which the Mammoth Springs owe much of their beauty is the numerous colonies of micro-organisms, olive-green, brown, yellow, and salmon-red, living in many, though not all of the springs, and thinly coating the wet terraces. Wherever the mineral waters are standing or flowing, except in very restricted areas close to the welling springs, deposition is probably active today.

The waters of these springs, comparatively uniform in character, and the deposits formed from them, are well represented in the following analyses:

Water from Jupiter Terrace Mammoth Springs in parts per million

Na	143
K	56
Mg	71
Ca	338
Al	trace
Fe	none
SO_4	528
S_2O_3	trace
S	none
HCO_3	871
CO_3	none
Cl	169
B_2O_3	undet.
SiO_2	46
	2,222

Travertine deposit[4] Main Terrace Mammoth Springs

SiO_2	0.26
Al_2O_3	.11
CaO	54.06
MgO	.66
NaCl	.26
CO_2	42.14
SO_3	1.34
H_2O	1.19
	100.02

[3] Weed, Ninth Ann. Report U. S. Geol. Survey 1887-8, p. 629.
[4] Analysis by Gooch and Whitfield, U. S. Geol. Survey.

As they escape from the ground, the hot waters contain a slight but sufficient amount of free carbon dioxide (undetermined in analysis) to hold all the lime in solution, and when bottled and properly sealed they stand indefinitely without precipitation. The water of the welling springs gives negative tests with phenolphthalein, but where it spreads out in pools of considerable size, it generally shows a pink color with the reagent at a distance of 5 or 6 feet from the orifice, indicating that the excess of gas has been lost, appreciable amounts of carbonate are present, and deposition has probably begun.

Boiling of the fresh spring waters causes slight effervescence, soon followed by copious precipitation. Prompt examination in the field laboratory of 11 samples of spring water, regardless of their history after coming to the surface, proved that the percentage of calcium precipitated by boiling varied from 69.6 to 82 per cent, averaging 77.7 per cent. It is concluded from these figures that the majority of the calcium escapes unprecipitated with the water from the active area.

The deposit itself, as shown by the analysis, is an impure calcium carbonate occluding, in some way, a little of practically everything found in the water. In ten analyses of travertine by Gooch and Whitfield, taken from the records of the U. S. Geological Survey, the calcium, which varied within narrow limits, averaged about 53.8 per cent, equivalent to 96 per cent of carbonate.

The first point to be noted in a discussion of the deposition process is that conditions prevalent in the Mammoth area today would inevitably lead to precipitation from the waters, even if the springs were absolutely devoid of organic life. Only spring water that finds its way *swiftly and smoothly* beyond the bounds of the active ground can be excepted from the general rule, and field observations indicate that very little if any of it would satisfy these conditions. All that is necessary for deposition is the escape of sufficient carbon dioxide from the water, no matter how accomplished. The warmth of the water, its agitation as it drips over the rims of the hot-spring basins, or flows down steep, rough channels, indeed the mere standing of the bicarbonate water in an atmosphere where the partial pressure of carbon dioxide is as low as that of the air we breathe, all must result in a loss of the gas which keeps the carbonate in solution, and while precipitation is probably never complete before the water escapes from the area, *it proceeds in places where little or no organic growth is visible, and*

in springs where organisms are relatively abundant precipitation is not obviously accelerated.

Rate of Precipitation of Travertine at Mammoth Springs.

In the summers of 1927 and 1928, tests of the rate of deposition of travertine were made at half a dozen points in the Mammoth tract in coöperation with Park Ranger M. L. Arnold. Cylindrical wooden blocks an inch in diameter and six or eight inches in length were exposed to the action of the spring waters for a recorded time (11 to 104 days), after which the blocks were collected and examined and the thickness of the deposit measured by calipers. The yearly rate of deposition was calculated from these figures on the assumption that conditions at any given point remained uniform. In many places in the field they undoubtedly fluctuate, the rate holding constant for a comparatively short time only; at others they are probably approximately the same for months or years. The computed rates varied greatly, as one might expect. Calculated in the above way, they ranged from 1.1 inches to 22.2 inches per year, with an average of 8.3 inches, though the number of determinations was not sufficient to make the average of any great significance. Weed[5] observed that articles set in the spray of falling water from the Mammoth Springs accumulated a crust of $\frac{1}{20}$ to $\frac{1}{16}$ inch in three days. In a year's time at these rates the deposit would amount to 6.1 and 7.6 inches, respectively. Hague,[6] in his unfinished manuscript on the geological features of the Yellowstone Park, remarks that the maximum rate of deposition in the Mammoth area, as measured by a driven stake, is 23 inches a year. Crude as they are, the different observations point to rates of deposition varying widely within similar limits, and both series show that precipitation is rapid for a geological process.

The incrustations formed on our blocks were not only generally free from any visible organism,[7] as shown by microscopic examination, but where an occasional green spot, due to algae, appeared, the thickness of the incrustation was not noticeably affected.

[5] Ninth Ann. Report U. S. Geol. Survey, 1887-8, p. 644.

[6] For the privilege of examining this manuscript the writer is indebted to Dr. George Otis Smith, former Director of the U. S. Geol. Survey.

[7] Weed's claim that objects immersed in the spray of the spring water acquire a pure white incrustation which changes to "a rich umber brown" after a few days' exposure was confirmed by none of our tests (Ninth Ann. Report, p. 644).

Function of Algae in precipitation of travertine.

Of the many species of plant life inhabiting thermal waters, Professor W. A. Setchell,[8] who has studied the question in the Yellowstone Park, regards only a small number of "blue-green"[9] algae, belonging to the genera Spirulina and Phormidium of significance in rock-building. They are photosynthetic, absorbing and transforming carbon dioxide and water into various organic substances under the influence of light. Within their gelatinous or woolly layers, Dr. Setchell finds, certain of these algae accumulate masses of travertine, shaped by the growing plant, while other species are free from such deposits; a fact indicating that the former perform some specific function in deposition. From the chemical viewpoint all photosynthetic plants, so far as they derive their carbon dioxide from the water, would be regarded as a factor in the precipitation of carbonate, though it is conceivable that some might be more active than others. Ferdinand Cohn,[10] in an investigation at the Carlsbad thermal springs, seems to have been the first to see in the absorption of carbon dioxide by algae a factor in the formation of travertine.

But do these algae accelerate precipitation to such a degree as to make them a factor of importance? At Mammoth Springs we have seen that deposition is rapid for a geological process. The deposit on a square foot of surface at the rate of only 1 inch per year would amount to 14 lbs. of calcite of normal density, 2.7; or with liberal allowance for porosity, say 10 lbs. If the precipitation were effected entirely by algae, an absorption of $0.44 \times 10 = 4.4$ lbs. of carbon dioxide, in addition to some free gas in solution, would be necessary in the formation of 10 lbs. of travertine; while an annual deposit of 8.3 inches per square foot would necessitate the absorption of more than 36.5 lbs. of carbon dioxide. Could these low organisms, *so sparse* in most parts of the Mammoth area, be responsible for any such consumption of gas, or even a significant portion of it? In standing pools where deposition from loss of gas is comparatively slow, the influence of algae may be more important, but in some such pools there is ***no visible growth***, and the writer has failed to find anywhere an obvious relation between more luxuriant growth and increased deposition.

[8] Personal communication.
[9] A technical usage. The color may be red, yellow, etc.
[10] Jahresber. u. Abhand. Schles. Gesell. Breslau 65, 1862.

PRECIPITATION OF SILICEOUS SINTER FROM HOT SPRING WATERS.

Much more extensive than the travertine deposits of the Yellowstone Park are the siliceous sinters. They are practically the only deposits found in the six typical geyser basins, the Upper, Midway, Lower, Shoshone, and Heart Lake areas, and those at West Thumb of Yellowstone Lake; they cover a large area along the east bank of the Firehole River, beginning opposite the Lone Star Geyser, and are found in parts of Norris Basin, at Geyser Creek, Lewis Lake, and other places. The area of these scattered irregular formations would be difficult to estimate, especially if old deposits in areas now inactive are to be included. They doubtless cover many square miles. Hardly any data on the thickness of such deposits are available. At a point in the Upper Basin where a test hole was drilled, the sinter measured 20 feet (C. N. Fenner). In some other parts of that locality it may be more, but in other basins probably less.

The siliceous sinters occur in well-marked drainage basins, and are derived from clear springs, relatively deep, often large and of high aggregate discharge. Over 70 per cent of the hot water discharged in the Park is of this type. The waters, many of which are near the boiling temperature, carrying a mineral burden of silica, associated with bicarbonate and chloride of sodium, as well as minor amounts of other constituents, are well illustrated by the following analysis:

Water of Giantess Geyser Upper Basin in parts per million	
Na	362
K	20
Mg	none
Ca	none ?
Al	none
Fe	none
F	20
SO_4	23
S_2O_3	3
S	1
HCO_3	9
CO_3	102
Cl	429
B_2O_3	15
SiO_2	372
	1,356

Siliceous sinter from near Tortoise Shell Pool, Upper Basin	
H_2O	13.90
SiO_2	83.35
Al_2O_3	.90
Fe_2O_3	.10
MnO	trace
CaO	.92
MgO	.09
Na_2O	.98
K_2O	.21
Cl	.15
SO_3	.05
	100.65
Less oxygen equiv. to chlorine	.03
	100.62

Properties of Siliceous Sinter.

Siliceous sinter, white, gray, or buff in color, is usually finely banded. Where frequently wet by spring water it remains dense and glassy; but in other places it becomes white and chalky, apparently by desiccation, and frequently disintegrates into sands and gravels. In composition it is chiefly hydrous silica, but like travertine contains a little of practically everything found in the spring water, as the appended analysis shows. No test by microscope or X-ray reveals any sign of crystallinity; the silica is entirely opaline. Geyserite is a name often given it.

Inorganic Conditions that Give Rise to Siliceous Sinter.

Controlling factors in the precipitation of uncrystallized silica are not so fully understood as those which govern the deposition of travertine. Lenher and Merrill,[11] working under carefully controlled conditions, found a definite solubility for flocculent silica in pure water amounting to 428 parts per million at 90° C., a figure scarcely affected by four per cent sulphuric acid, but falling off rapidly with temperature. Ignited silica and the mineral chert gave figures considerably lower. According to P. G. Nutting,[12] distilled water dissolves about 300 parts per million of precipitated silica at 100° C. Siliceous sinter from Yellowstone Park, similarly tested by him, showed a solubility only about one-tenth that of flocculent silica. Spring waters varying in silica content all the way from 58 to 717 parts per million are found in these alkaline springs, generally in contact with a lining of geyserite, with which obviously they are not *all* in equilibrium. Left to stand in glass bottles, silica is almost never precipitated from such waters, even after months or years. In only one sample out of several score was precipitation actually observed, and that was from water collected in the Norris Basin and unusually high in silica. Without attempting a complete explanation of the facts, we may remark that this precipitation appears to be an irreversible process, perhaps because of a progressive dehydration in the solid phase which first separates. But defective as our information is, we possess enough to show

[11] J. Am. Chem. Soc., *39*, 2630, 1917.
[12] J. Wash. Acad. Sci., *22*, 261, 1932.

that conditions now operative in the Yellowstone Park are capable of precipitating silica from alkaline spring waters without any intervention of living organisms.

Effect of Evaporation on Alkaline Spring Waters.

When waters of this class are evaporated in the laboratory, a deposit of banded structure, clinging fast to the dish, separates before dryness is reached. The addition of hot water may dissolve some, but by no means all, of the precipitate. Evaporation is not only general in the geyser basins but observation indicates also that deposition of silica from the hotter waters is due largely to this cause. Bunsen believed that all the siliceous sinter of Iceland was the result of the same agency.

Result of Freezing Alkaline Waters.

Silica is also separated from these same spring waters by freezing, though not by mere cooling, as proved by Gooch and Whitfield in the laboratory of the U. S. Geological Survey, and recently confirmed in the Geophysical Laboratory. Rangers Hanks, Baker, Phillips, and Arnold have each sent to Washington samples of soft opaline silica, collected along the edges of hot-spring effluents in the Upper and Norris Basins, immediately following severe winter weather; material which, they concluded, had been formed by the freezing of the alkaline water. Many particles of this flocculent silica showed characteristics similar to those obtained by freezing, in the laboratory, Yellowstone waters of the same type, namely, elongation in one or two directions, as if they had been squeezed out by the ice as it formed; and a refractive index almost as high as that of silica glass, which, of course, is anhydrous.[18] While not a sinter in itself, this soft silica may be cemented to older formations by subsequent action of the alkaline siliceous spring waters, and the amount of it in places may greatly exceed the silica formed by evaporation. Material of similar appearance, strikingly different from sinter, has been seen by the writer in the Upper, Lower, and Monument Basins. How much of it is washed away and how much eventually becomes hard sinter is a question that remains unanswered.

[18] All optical and other microscopic work was done by H. E. Merwin.

Formation of Siliceous Sinter in the Springs.

There is at least one other inorganic factor besides evaporation or freezing to which the formation of siliceous sinter is due. The presence of sinter linings in the great majority of alkaline springs suggests a separation of silica *without evaporation.* Of course, it may be possible that the linings have been gradually built up by evaporation at the outer edges of the spring. The question was put to a test by leaving wooden blocks wholly submerged in a number of different springs for a period of 8 months or more. Only one of them accumulated any silica. That was in a spring in the southern part of Norris Basin, where the needles of a pine spray were beautifully frosted to a thickness of 0.75 to 2.5 mm. in about 8 months. Subsequently, a block of wood gave similar results. We know next to nothing about the *process.* We cannot say positively whether silica is now precipitating in all these hot waters, *generally* at a rate exceedingly slow, or whether the silica linings of the springs were formed in another way.

Rate of Deposition of Siliceous Sinter.

That geyserite accumulates at a rate very much slower than travertine has long been recognized. Weed,[14] describing his observations on this point in 1889, says that deposition of silica from inorganic causes is very slow in the Yellowstone Park outside the Norris Basin. Several rates, without details of determination, are given. At Liberty Geyser, it amounted to $\frac{1}{20}$ of an inch in 18 months; at the Model Geyser, $\frac{1}{120}$ inch in 9 years; at a spot near Castle Geyser, $\frac{1}{100}$ to $\frac{1}{60}$ inch per year, not wholly due to inorganic causes. Weed's estimate of the amount of silica deposited at Old Faithful Geyser was scarcely more than $\frac{1}{20}$ inch per year. The average of these figures is about 0.6 mm. yearly.

In our tests cylindrical wooden blocks like those already described (p. 376) were left in many of the alkaline springs for recorded times, varying from about 3 months up to nearly a year. Some were left floating on the surface of the springs, some wholly submerged in the water, and still others exposed to the intermittent splash of geysers. The maximum thickness of the generally uneven film of silica was taken with the

[14] This Journal [3] *37*, 356, 1889.

calipers. In half of the 27 tests not more than a trace of silica was obtained. In the other half the rate varied from 0.1 mm. to 4.0 mm. per year, with a mean of 1.1 mm. The average of all the determinations was 0.5 mm. a year.

Acceleration of Silica Deposition.

Comparatively slight interference with natural conditions greatly accelerated the speed at which silica is deposited from Yellowstone springs. Thus, two blocks set out in the path of small gushing streams of hot water on the brow of Porcelain Terrace, Norris Basin, were completely buried, in 11 months, with sinter indistinguishable from the surrounding terrace. The maximum rate of deposition on the two blocks reached 26 mm. and nearly 35 mm. per year, respectively. When a sample of the water was sought for a silica test, the two streams had both disappeared. Spring water close by contained 0.666 g. silica per liter. It has been assumed that the rate of deposition in this place was accelerated by the presence of the wooden blocks, but it is possible that the result was merely the natural accumulation from a water unusually high in silica. Additional tests in *flowing* spring water lower in silica are needed.

Another instance[15] of the rapid precipitation of silica from alkaline water was observed at the Upper Geyser Basin within the last decade. To reduce its temperature for use in a swimming pool, the water of a small geyser (The Solitary) was conducted over a set of wooden cooling frames built on the steep hillside. The geyser erupted about once in five minutes, drenched the frames and left them dripping. The wooden bars were never dry, yet they became heavily incrusted in about 12 years with warty, wedge-shaped stalactites, the longest 8 inches (203 mm.) in length. This would amount to a rate of 17 mm. per year. The average for all the stalactites was certainly less than half this figure. There was nothing unusual in the composition of the stalactites, nor was the water of the geyser remarkable. It contained 0.365 g. silica per liter, an amount nearly equaled by about half the analyzed waters of the Upper Basin, and exceeded by some of them. In the mind of the writer there is little doubt that the great

[15] A part of this information was obtained from Mr. H. P. Brothers, builder and operator of the pool.

gain in the rate of deposition is the result of increased evaporation. The longer stalactites developed on the *lower* bars of the cooling frames. With eruptions proceeding once in five minutes, 1,230,000 of them must have occurred during the growth of the stalactites. Allowing for considerable variation in the action of the geyser (it varied comparatively little when observed) less than two hundred-thousandths of a millimeter of deposit could be credited to the average eruption. An analysis of one of these stalactites follows.

Stalactite from water of Solitary Geyser.

H_2O	7.92
SiO_2	90.40
Al_2O_3, etc.	1.36
CaO	.22
MgO	.08
	99.98

Influence of Organisms in the Formation of Siliceous Sinter.

As to the influence of algae in the formation of the siliceous stalactites, no organic growth except an occasional bright green spot, that appeared to be purely incidental, was associated with any of them. Nor was there the least indication that any of the films of silica deposited on the test blocks was due to an organic agency. In the great majority of the hot alkaline springs the clear waters are entirely free from visible organisms, and Dr. C. B. van Niel, microbiologist, who, with Mr. Lewis A. Thayer, made observations in the Park in 1929, pronounced them sterile. Weed says that the upper limit of the temperature range within which plant life occurs is 185°F. (85°C.).[16] Very small growths do occasionally occur at such temperatures, but they bear no relation to deposition. The writer discovered a tiny patch of fringe-like white organism living in the Giantess Geyser at 92°C., and Dr. van Niel found another of similar appearance in the Punch Bowl, where the temperature was also above 90°C. Both occurrences were identified by him as bacteria. Professor Setchell also collected bacteria "in the hottest waters (75°-89°C.) inhabited by thallophytes." The writer has found few organisms of any kind in these springs at temperatures much above 70°C. Yet despite the sterility of the hottest waters they almost always contain precipitated silica, and if the spring overflows, a sheet of silica, continuous

[16] Ninth Ann. Report U. S. Geol. Survey, 1887-8, p. 625.

with the lining of the spring, commonly extends all the way down to the lake or stream into which the hot water is discharged.

On the *extreme outer edge* of alkaline hot springs, where temperatures fall decidedly, gay growths of algae, generally in the form of a narrow band, are often found; and along the outlet streams, especially on the cooler edges, they also occur.

Regarding the formation of the extensive sheets and terraces of silica covering the active portions of the geyser basins, the writer, founding his conclusion on the *small quantity* of organic growth visible in such places, is unable to see in the algae a factor of importance. In certain restricted areas beautiful displays of color due to plant life are exposed to view, but even then they usually form *merely thin coatings* on the surface of the sinter. The slow rate at which most silica is deposited may leave some room for doubt in this matter, but much stronger evidence than that now forthcoming will probably be needed to convince the unbiased reader of the paramount importance of organic agencies in the building up of deposits for which we have already simple explanations based on both experiment and field observation.

Siliceous Deposits Strongly Indicative of Organic Influences.

On the other hand there are areas within the limits of these alkaline basins where hot-spring outflows, cooled to tepid temperatures, collect in very shallow hollows, where organic growth is obviously more luxuriant, and the silica that precipitates assumes mushroom-like forms, strongly suggestive of organic influences. Weed and Setchell have both described these curious forms. Gelatinous stem-like structures, principally of Phormidium (Setchell), held erect by the lifting power of an enclosed gas bubble, rather than by their own strength, grow upward till they reach the surface of the pool, where they develop laterally into a crown. Meanwhile, silica has been gradually forming casts about the "stems," and at the crown more is deposited at a relatively rapid rate. Where the "mushrooms" are crowded together, the crowns form a continuous roof (Setchell). According to Weed the flow of water becomes choked by the vegetable growth, evaporation becomes more effective, and the pool eventually dries up. The silica first separating is said to be a jelly. A formation

of $1\frac{1}{8}$ inches of this material in $2\frac{1}{2}$ months, equivalent to an annual deposit of 5.4 inches, was observed by Weed.[17] That the deposition proceeds much faster than that of ordinary geyserite is not to be questioned though the product is not nearly so dense as the latter. "In physical character," says Weed, "the sinters resulting from algous vegetation differ from those formed by evaporation, or other inorganic causes, by their greater lightness and opacity. They are often soft and easily crushed, and sometimes soil the fingers; their structure is easily distinguished from that of other forms of sinter." (Op. cit., p. 357.) Weed's belief that sinter formed by algae was purer[18] (freer from clay) than other sinter is not confirmed by the few analyses of the writer.

Whether the rôle of algae in the formation of these peculiar sinters is functional, or merely incidental, like the part of the cooling frames in the development of the siliceous stalactites (p. 382), is an interesting problem for the biologist. Setchell has pointed out that the same few species of blue-green algae are associated with both travertine and silica deposits. In 1929 Dr. C. B. van Niel[19] made the suggestion that all these organisms necessarily absorb *water* as well as carbon dioxide, and thus their normal growth should tend to concentrate the mineral water in which they live. In large springs, sufficiently cool to support life, or in many of the outlet streams, such masses of vegetable growth as the writer has seen could cause no appreciable difference in concentration, but in shallow pools of standing water this factor would become more important. Whether it would ever reach a magnitude comparable with that of evaporation is a question we may leave to the plant physiologist. Sinter deposits either caused or accelerated, and obviously shaped, by organic influences may be found at "Algous Terrace," "Specimen Gardens," and in the outlet of Emerald Pool (Weed), all in the Upper Basin, in a remarkable section at West Thumb between the Ranger Station and the lake, and perhaps in other places. That the sum of all these areas forms an important part of the total expanse of siliceous sinter deposits was not concluded by the writer from his own observations, but it would be worth while for one especially interested in the problem to make careful estimates of each class.

[17] This Journal [3] *37*, 356, 1889.
[18] Op. cit., p. 358: Am. Geol. *7*, 54, 1891.
[19] Personal communication.

Sinter Deposits from Cold Diluted Alkaline Spring Waters.

Bars of siliceous sinter of considerable extent have been observed in streams receiving the discharge of alkaline springs, like Firehole River, Witch Creek and Rabbit Creek, and at West Thumb a sheet of silica, following the outflow of hot water, projects out from the shore into Yellowstone Lake along a wide front. *In spite of strong dilution* silica has been deposited from hot-spring waters.

In Rabbit Creek, a small stream flowing into Firehole River at the southern end of Midway Basin, precipitated silica has built up remarkable sluice-like structures in midstream, one of them 75 feet long by 3 feet wide and perhaps a foot higher than the stream level at the lower end. The water, while not appreciably diluted, has been decidedly cooled. No warm-water algae were obviously associated with this deposit, and according to present views diatoms have no part in the formation of sinter.[20] These occurrences remain unexplained.

Silica Deposited by Diatoms from Hot-Spring Effluents.

In an article on "Diatom marshes and diatom beds in the Yellowstone National Park," Weed[21] mentions the discovery by Professor Farlow of a species of diatom among the algae from one of the hot springs of the Park. Dr. H. E. Merwin has repeatedly recognized these organisms in many samples of deposits taken directly from thermal springs, and in one small portion of such a deposit from an alkaline spring in the River Group, Lower Basin, Dr. Albert Mann of the Smithsonian Institution actually identified 57 species and varieties. Working under his instructions we collected a large number of specimens in waters of measured temperature, and examined them microscopically within a few hours. Diatoms were usually present, but in specimens from *hot* water they were, as expected, always dead, generally empty shells. Living diatoms were never found in water much above 40°C. There is no evidence that diatoms adapt themselves to hot waters, or that they are instrumental in forming siliceous sinters; the silica which they precipitate is derived from water, cold or barely warm. Diatom shells in hot springs have probably been washed or blown in.

[20] Personal communication from Dr. Albert Mann.
[21] Botan. Gazette **14**, 117, 1889.

Biologists have pointed out the remarkable power that diatoms possess in segregating silica from water very low in that substance. Investigations by Weed (op. cit.) show that they also thrive in cooled spring waters *high* in silica. He has discovered extensive diatom bogs covering many square miles of ground in meadows adjacent to Norris Basin, the Upper and Lower Basins, Lewis Lake, and Pelican Creek. "In most of the cases observed these diatom marshes cover ancient deposits of siliceous sinter, diatoms growing in the cooler waters of the decaying springs or their overflow, and covering the sinter beds until even the tops of the cones are submerged beneath the ooze and the vegetation it supports. . . . . Such marshes also occur, however, where the cooler alkaline waters of the geysers and boiling springs overflow the natural surface of the ground." Diatoms of several species were identified in material of this sort by Dr. Francis Wolle of the Smithsonian Institution. White pulverulent material on the margin of some of these bogs proved on microscopic examination to be the dried remains of the same species, showing that the ooze is slowly passing into diatomaceous earth. Diatom beds exposed in draining low ground to a depth of 3 or 4 feet, in places 5 or 6 feet, were found in the course of these explorations. Geologists are indebted to Weed not only for his investigation of extensive diatom deposits, but also for his interesting evidence of the final stage in the history of certain alkaline thermal springs.

General Conclusions of Weed and Setchell on the Importance of Algae in Deposition.

Where our observations on deposition are comparable, the writer's for the most part confirm Weed's; it is principally in estimating the degree and extent of organic and inorganic agencies that we differ. The following citations fairly represent Weed's conclusions: "Travertine formed without the presence and aid of plant life forms but a very small part of the bulk of the Mammoth Hot Springs deposit."[22] "Though evaporation is certainly an efficient agent, particularly in the dry air of the Park, producing some of the most beautiful and striking forms of (siliceous) sinter known, yet the deposits of the Yellowstone (excepting those of Norris

[22] Ninth Ann. Report U. S. Geol. Survey, p. 646, 1887-8.

Basin), are but partly due to this cause, and, as already stated, are chiefly formed by a separation of silica by the vegetable life of the hot water."[28]

Dr. Setchell's opinion on the subject, arrived at by entirely different methods, is substantially the same as mine, perhaps even less favorable to organic agencies, because he has not considered the work of diatoms. His words are: "Morphological studies, such as are being reported upon, with the botanist's point of view paramount, do not even yet throw much light on the important question of the exact influence of algae in rock building. They are not responsible for anywhere near all of the deposit, but they are in certain areas in more or less close association with it."

SUMMARY.

To the extent that algae absorb carbon dioxide from the Mammoth Spring waters, they must be regarded as a factor in the precipitation of travertine. *Geologically* their influence is held to be unimportant for the following reasons:

1. Inorganic causes now operative in the Mammoth area, involving loss of carbon dioxide in several well-recognized ways, account satisfactorily for the deposits.
2. Actual tests with wooden blocks in half a dozen places yielded incrustations of travertine, generally quite free from any organic growth.
3. The rate of deposition is relatively rapid, and it is not believed that the *sparse growths* of algae, characterizing the Mammoth area generally, could be capable of absorbing the great amounts of carbon dioxide that such a speed of precipitation demands.
4. No obvious relation could be discovered between the more luxuriant growth of micro-organisms in a few places and increased deposition.

The dense, hard, siliceous sinters that line the majority of the springs and that cover the terraces and floors of the geyser basins and allied areas, as well as the sinter gravels derived from them, are concluded to be the result of inorganic agencies. Laboratory experiments, field observations and tests prove that silica is deposited from alkaline spring waters by evaporation, by freezing, and in places by direct precipitation from hot-

[28] This Journal [3] *37*, 353, 1889.

spring water without concentration. Not only are the hotter waters practically sterile, but also the absence of organisms, or their scanty growth over wide areas in these basins, points to an unimportant geological agency.

Contrasted with these deposits are those from spring waters nearly cold. In certain shallow depressions supplied by the cooled outflow of alkaline springs an abundant growth of algae is associated with an obviously rapid deposition of silica in distinctive forms. The speedier formation of silica may be a consequence of increased evaporation due to exposed plant surface. It should be partly dependent on the functional activity of the algae (van Niel). Weed's estimate of the extent of these areas is much higher than the writer's.

Sheets of silica sinter extending out into lakes or forming bars in streams into which alkaline springs discharge are not satisfactorily accounted for on inorganic principles. They may be due to organic influences.

Weed's explorations indicate that myriads of live diatoms in the meadows adjacent to Yellowstone geyser basins are at work forming shells which eventually grow into beds of diatomaceous earth. While these deposits are not siliceous sinter, they appear to have the same origin and are thus to be regarded as a distinctive phase of the same general geological process.

Geophysical Laboratory,
Carnegie Institution of Washington,
June, 1934.

DISCUSSIONS AND COMMUNICATIONS.

HIATUS BETWEEN THE LEMONT MEMBER OF THE CARLIM LIMESTONE AND THE LOWVILLE LIMESTONE IN CENTRAL PENNSYLVANIA.

In a paper on "The Ordovician Bentonite Beds," in central Pennsylvania, by R. R. Rosenkrans, which appeared in the February issue of the Journal, in the year 1934, on page 131, the following paragraph occurs: "Data have been presented which point to the conclusion that the 'Lemont member of the Carlim' of the type section is in part equivalent to the beds which Butts (who proposed this term) has mapped as being much younger in age. This interpretation of the data indicates that the supposed hiatus, equivalent to several thousand feet of sediments, which has been said to exist at the base of the quarry rock of the Bellefonte section is not present." It is not my desire to take up valuable space in the Journal for a full discussion of this matter, but I feel that I am entitled, in self-defense, to record here my reaffirmation of the existence of this hiatus, the position of which is, as nearly as I can identify horizons from Mr. Rosenkrans' sections and descriptions, at the place of bentonite bed "C" in section No. 3, plate 3, page 121, of the February number of the Journal. The subject will be adequately discussed and proofs given in the bulletin on the Bellefonte quadrangle in course of publication by the U. S. Geological Survey, which, it is hoped, will be published in the next year or two. In the meantime those who are interested can find the essential facts in the following publications:

Variations in Appalachian stratigraphy, by Charles Butts.

Journal of the Washington Academy of Sciences, vol. 18, No. 13, July 19, 1928.

Sixteenth International Geological Congress, Guidebook 3, Excursion A3, 1932.

Geologic Map of the Appalachian Valley of Virginia with explanatory text, by Charles Butts, pp. 15-18, 1933.

CHARLES BUTTS.

WASHINGTON, D. C.

THE VOLATILE TRANSPORT OF SILICA.

In connection with the very valuable article under the above title by J. W. Greig, H. E. Merwin and E. S. Shepherd, which appeared in the January number of this Journal for 1933, it may be interesting to note that R. Willstaetter, H. Kraut and K. Lobinger, of the Chemical Laboratory of the Bavarian Academy of Sciences, working at temperatures well under 100°C., also observed the volatilization of silica. In two articles[1] which appeared in 1925 and 1928 respectively, they described experiments in which solutions of silicic acid were prepared from silicon chloride. After the last traces of chlorine-ion had been removed by suitable methods of purification, the solutions, containing about 2.5 grams SiO_2 in a volume of 200 cc. were concentrated to a volume of about 50 cc. in the course of approximately one hour[2] in a vacuum distillation apparatus. In all cases the temperature was maintained far below 100°C., in some cases as low as 15°. The quantity of SiO_2 found in the distillate varied between a fraction of a milligram and several milligrams. It was, however, not possible to control the conditions of the experiment so as to obtain consistent results; it even happened in some cases that nothing, or almost nothing, was contained in the distillate.

In a later article,[3] the same authors describe similar distillation experiments with solutions whose hydrogen-ion concentration was adjusted to a pH of about 3.4 by means of dilute hydrochloric acid, the solutions being about 1/700 normal HCl at the beginning of distillation. At the indicated pH, the silica was present chiefly as monosilicic acid. From such solutions only very small amounts (several tenths of a milligram) of SiO_2 were volatilized. The authors suggest, on the basis of these results, that the condition for the volatilization of SiO_2 at low temperatures is not its presence in the form of monosilicic acid, as had at first been suspected, but its presence in a less hydrated form, in analogy to boric acid.

RUTH D. TERZAGHI.

[1] Willstaetter, R., Kraut, H., Lobinger, K., "Zur Kenntnis der Kieselsaeure," Berichte d. deutschen chem. Gesellschaft, vol. **58**, pp. 2462-2466, 1925.
——————, "Ueber die einfachste Kieselsaeure," Berichte d. deutschen chem. Gesellschaft, vol. **61**, pp. 2280-2293, 1928.
[2] Personal communication.
[3] "Zur Kenntnis der Monokieselsaeure und Dikieselsaeure," Berichte d. deutschen chem. Gesellschaft, vol. **62**, pp. 2029-2034, 1929.

TECHNISCHE HOCHSCHULE,
VIENNA, AUSTRIA.

SCIENTIFIC INTELLIGENCE.

Physics.

Zeiss Nachrichten, Heft 4, 1933. Pp. 40; 20 figs. and photographic reproductions. Jena, 1933 (Carl Zeiss).—This issue should be of especial interest to those dealing with microphotography as the contents comprise chiefly recent improvements in this field, well explained and illustrated, including methods of illumination and ultraviolet and infra-red photography. A. T. W.

The Phenomenon of Superconductivity; by E. F. Burton. Pp. 101; 28 figs. Toronto, 1934 (University of Toronto Press and University of Chicago Press, $2.50).—Superconductivity, the property of certain metals to conduct electricity with almost perfect freedom when cooled nearly to absolute zero, has defied explanation since its discovery by Kamerlingh Onnes in 1911. Seldom has a phenomenon so startling and seemingly so simple as this baffled theorists for so long a time. This book by the director of the Physical Laboratory of the University of Toronto, one of the few institutions in the world equipped for this low-temperature work, describes the experimental methods of producing and measuring low temperatures, and the facts known about superconduction, together with a brief account of the theory of electrical conduction in metals and mention of some of the proposals in explanation of superconductivity. A. T. W.

Geology.

Principes de Géologie; by P. Fourmarier. Pp. 882; 537 figs. and 6 pls. Paris, 1933 (Masson et Cie., 250 francs).—Professor Fourmarier offers us a work extraordinary in its breadth, touching at great length on many branches of geology. One's first reactions must consist of astonishment and respect for the breadth of knowledge required to write easily and authoritatively what is more an encyclopedia than a textbook. As a reference work in at least a number of the fields on which it touches, it cannot fail to be useful. Its value as a text must necessarily be a matter of opinion. Geologic texts produced in Europe, especially Continental Europe, tend to be compendia, whereas those written in America tend to be more closely knit, and to set forth the relationship between the several geologic processes and their products, than do those from across the Atlantic. American educators have generally regarded the philosophy underlying the geologic processes as of greater significance in an elementary education in geology than the assimilation of a vast array of facts. As a result, the American viewpoint

toward Professor Fourmarier's volume would be unfavorable to it as a text, but would surely regard it as a valuable work of reference.

In at least one respect, it approaches nearer to American custom than do its contemporaries. It has been the practice on the Continent to make a sharp distinction between geology proper, and those branches of physiography—notably geomorphology and certain phases of oceanography and meteorology—which are in American opinion intimately allied to it. The latter subjects are considered in Europe as a part of geography, and accordingly, they have been given relatively little consideration in geologic teaching, to the detriment (in the American view) of geology. Professor Fourmarier, however, devotes more attention to land forms than do some American texts, and in addition he treats meteorology and physical oceanography in separate chapters.

The facts are well and simply set forth, and the examples, although few in number, are not provincial but are drawn from many parts of the world. The organization of the book is perhaps its most outstanding feature, and requires special comment. Following a vigorous introduction on the methods of geologic research, the work is divided into five parts:

I. Kinds of rocks—weathering and erosion as related to the rock cycle—the Earth as a planet—Earth origin.

II. The making of rocks (sedimentary and igneous).

III. Evolution of rocks—Folds, faults, earthquakes, joints, metamorphism, filling of open spaces, theories of diastrophism, interpretation of geologic maps.

IV. The continental masses. (A description of the broad lithologic and structural features of each continent, stressing the great shields, the parallelism of successive fold movements, and the distribution of geosynclines.)

V. Physical geography, here including paleogeography, climatology, oceanography, the cycle of erosion, hydrology, drainage modifications, land forms, and shore features.

This arrangement, to the American mind, seems not only strange but illogical, because it breaks up the treatment of several topics that we think are better treated as units. Weathering is considered both under climate and in connection with the rock cycle. Stratigraphic principles are considered both under kinds of rocks and under the formation of rocks. Shore processes are considered both under marine deposits and under land forms. Each of the types of continental deposit is considered in two places. This arrangement results in a good deal of overlapping, allows of no systematic treatment of any one process, and is complicated further by the lack of an index, which somewhat diminishes the value of the book as a reference work. Furthermore, it brings together some rather strange companions. For example, the chap-

ter on the Filling of Open Spaces in rocks treats just two processes —the origin of veins and geodes, and the origin of oil pools—the connection between which is purely nominal. Again, in the discussion of igneous rocks a distinction is made between (1) volcanic rocks and (2) igneous rocks of ancient date, by which denuded intrusives are meant. From a strictly genetic point of view, the emphasis perhaps ought to be placed on the distinction between extrusive and intrusive, rather than on a time classification.

In dealing with the origin of the Earth, the author states his preference for the Nebular Hypothesis, which he treats at length, dismissing the more modern ideas based on tidal disruption with very brief statements.

The bulky illustrative material (537 figures) consists entirely of diagrammatic line drawings, used deliberately in place of photographs as being clearer and more understandable. All but about a dozen are two-dimensional, and whereas many are admirably clear, some would convey a better impression of the features they aim to portray, if they were drawn as three-dimensional blocks.

The foregoing statements represent an attempt to set forth circumstantially all the shortcomings of the book as they appear to the reviewer, but the reader must keep in mind that nearly all the criticisms are based on the viewpoint of American education. The scope of the work, the facts set forth, and the clarity with which they are expressed, are international in character and can not fail to excite admiration. In America, investigator and teacher alike will find Professor Fourmarier's treatise both sound and useful. It is unquestionably worthy of careful perusal by geologists in all parts of the world. RICHARD FOSTER FLINT.

Geology of Puerto Rico; by HOWARD A. MEYERHOFF. Monographs of the University of Puerto Rico, Ser. B, No. 1, 1933. Pp. 306, 45 figs., and map.—Those interested in the geology of Puerto Rico and of the Antillean region in general will find much to interest them in this excellent discussion. The author has drawn not only upon his own considerable field experience of the island, but upon a large body of earlier published material. The treatment is refreshing partly because the language used has personality and picturesqueness, and partly because the arrangement of topics is unusual. The discussion begins with a physical and historical setting, proceeds to the geologic history, and then treats "geologic materials"—rocks, structures, mineral resources, and soils. There follows a lengthy discussion of processes now operating, and the author clearly sets forth the outstanding unsolved problems. The treatise is written so as to serve as a handbook for the non-technical Puerto Rican reader, and, apparently for this reason, contains a very extensive glossary of geologic terms. A colored geologic map, scale about five miles to the inch, clearly portrays the areal geology.

The core of the island consists chiefly of Cretaceous volcanics which were folded, locally in the Appalachian manner, along NW.-SE. axes, overturned to the NE., and cut by intrusives in a late Cretaceous movement which the author refers to as the Antillean Revolution. Mid-Tertiary marine sediments were deposited on the eroded flanks of the Antillean mass and were uplifted to form coastal plains. Two pronounced erosion surfaces, the product of fluvial agencies, are well preserved in high benches, and resistant ridges. The St. John peneplane is regarded as Miocene, and the Caguana peneplain as of Pliocene date.

Post-Tertiary movements accompanied by block faulting caused severance of the present island from St. Croix and Santo Domingo. The author correlates certain emerged barrier reefs with late Pleistocene glacial control of sea level.

The book as a whole is illustrated with photographs, sections, and some good block diagrams, some of which would be more immediately instructive if their scale and orientation were shown. This, however, is a small criticism of an apparently very fine piece of work. RICHARD FOSTER FLINT.

The Dinosaurs: A Short History of a Great Group of Extinct Reptiles; by W. E. SWINTON. Pp. xii, 233, 25 pls., 20 text figs. London, 1934 (Thomas Murby & Co., price 15/- net).—Dr. Swinton has done an excellent piece of work in gathering for this compact volume about all that is known concerning a group of animals which were, for many millions of years, the dominant note in the terrestrial fauna of the world. The average reader will be amazed, not only by the magnitude of some of the forms discussed, but by their remarkable numbers and the range of size, form and adaptation which they display. The scientist who studies the remains of these creatures at first hand will also benefit greatly by the perusal of this book, for the reviewer knows of no other single publication which contains so complete an array of facts concerning dinosaurs as this. Dr. Swinton discusses the former distribution of these animals, their origin, general anatomy, and classification and then, taking each group in succession, the author gives us a detailed picture of all of the principal genera and species. His chapter on dinosaurs and disease discusses the pathologic condition so frequently met with in the fossils and attempts to interpret the causes. This leads up to the problem of their extinction, invoking physiological, biological and geographic factors, but attributing the final passing of the race not to any one, but to a complex series of causes, based on a fundamental geologic change, complicated by racial old age, lack of plasticity of the dinosaurs themselves, with, maybe, the added factors of food deficiency, climatic variation, and possibly epidemic disease. A discussion of the field and laboratory technique and two appendices complete the volume. The book is excellently made and convenient in size, and

the restorations are fresh and interesting. Some of these are from models posed in a naturalistic environment. The pen drawings which illustrate the anatomy, however, lack clarity because of their technique. The book, which is to be highly commended, is singularly free from errors of fact or conclusion. R. S. L.

Stratigraphy of Western Newfoundland; by CHARLES SCHUCHERT and CARL O. DUNBAR. Pp. 104; 11 pls., 8 text figs. (Memoir 1 of the Geological Society of America).—This work on the stratigraphy of Western Newfoundland is doubly welcome as it gives the first adequate presentation of the geology of Western Newfoundland for over 60 years and it is the first of the Penrose series of memoirs to be published by the Geological Society of America. Both the authors and the Society should be congratulated.

The rocks of Western Newfoundland belong to the Basement Complex and the Cambrian, Ordovician, Devonian and Carboniferous Systems. There is no Middle Cambrian, probably no high Ordovician, no Silurian, and no Middle and Upper Devonian.

The Lower Cambrian is termed the Labrador series and is divided into three formations which, in ascending order, are the Bradore, Forteau, and Hawke Bay. The Bradore formation is an arkose without determinable fossils; the Forteau formation consists of shales and reef, sandy, and oolitic limestones; and the Hawke Bay is a pink quartzite with some dolomite in the upper part. The total maximum thickness of the Lower Cambrian is found in Bonne Bay where over 2200 feet have been measured. The Upper Cambrian is best known on the southern shore of Cape St. George where the strata have been designated the March Point formation and consist of dolomite and siltstone with a total thickness of 930 feet.

Ordovician strata form most of the northern half of the western coast of Newfoundland. They are placed in five series which, in ascending order, are Green Point, St. George, Table Head, Long Point, and Humber Arm. The Green Point series consists mostly of pale olive-green shales. It is assigned to the Canadian. The St. George series is composed largely of dolomite and is also assigned to the Canadian. The Table Head series is very fossiliferous and consists mostly of limestones but black shales are present at the top. This series is assigned to the Chazy. The Long Point series consists of shales and limestones and is assigned to the Black River. The Humber Arm series is composed mostly of green shales and locally at the base is the remarkable Cow Head breccia or conglomerate. This series has a thickness estimated to be between 8000 and 10,000 feet. Few fossils are present and these do not permit precise dating except that fossiliferous parts are not younger than Middle Ordovician. The higher parts of the series may be of late Ordovician age. The Cow Head breccia

is related to thrust faulting, the rocks having fallen from an overriding thrust block, and it is considered probably that in places the unit may pass into real fault breccias. The total thickness of the Ordovician strata is between 10,000 and 15,000 feet.

The Devonian, present only on the outer shore of the St. George peninsula and designated the Clam Bank series, consists of shales, sandstones, thin limestones, and at the base are conglomerates. The prevailing color seems to be red and the thickness exceeds 1600 feet.

The Carboniferous consists at the base of the Windsor series of Mississippian age, composed of conglomerates, sandstones, shales, gypsum, and limestones. The thickness is 3450 feet. Overlying the Windsor series are strata assigned to the Pennsylvanian. These are of continental origin and consist of shales, sandstones, and conglomerates with a thickness of 3000 feet. The total thickness of the Carboniferous is 6450 feet (erroneously given as 9450).

The Paleozoic strata lie west of the Long Range, composed mainly of ancient crystallines, from which they are separated by a zone of thrust folding. There is more or less deformation and the beds in many places stand at high angles, and they have been variously intruded by lavas of different ages. The sediments composing the Lower Paleozoic strata were deposited in the St. Lawrence portion of the Appalachian geosyncline. These sediments were derived from the New Brunswick anticline and the Laurentian Shield. The strata were first deformed in connection with the folding that produced the Cow Head breccia. This folding is considered connected with the Taconian orogeny. It is suggested that the Acadian orogeny may be responsible for some of the intrusive bodies. The Carboniferous strata were deposited in the Northumberland embayment which extended across the New Brunswick geanticline from the Acadian to the St. Lawrence geosyncline. Appalachian orogeny is shown in the folded and faulted strata of Carboniferous time. Following the Carboniferous, Newfoundland was reduced to a peneplain, now expressed in the nearly flat tops and accordant summit levels of the highlands of the west coast. This peneplain was uplifted and tilted eastward in the Cenozoic.

W. H. TWENHOFEL.

UNIVERSITY OF WISCONSIN.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

American Inventors; by C. J. HYLANDER. Pp. xv, 216; with 38 drawings and 16 photographs. New York, 1934 (The Macmillan Co., $2.00).—This is an excellent set of sketches that describe the long and often heart-breaking labors which led to the principal American inventions. The chapters contain brief biographies of the inventors and are illustrated with good drawings

of the early models. They are made entertaining with racy anecdotes and comments, of which the following is a fair example: "The Fenians now offered Holland $23,000 with which to build a full-sized craft. The modest hope that the submarine might cross the Atlantic and destroy the English fleet was no doubt a big factor in loosening their pocketbook clasps." It is a safe guess that any intelligent boy who wants to know about the great inventions of the 19th century would be pleased with this book.

HENSHAW WARD.

Sky Determines; by ROSS CALVIN. Pp. xiii, 354; with 12 photographs. New York, 1934 (The Macmillan Co., $2.50).—The rector of a church in Silver City, New Mexico, has prepared this description of his state with much skill. He tells of climate, mountains, and people with a contagious enthusiasm for the romance of his subject. It is to be feared that many readers of the first few pages will be deterred by remarks about "a new and creative interpretation," "thinking comprehensively and penetratingly," "a new understanding." Readers who persevere will soon find themselves in the midst of very different matters: the million bushels of apples, the "devilish instruments" of the yuccas, the Gila National Forest as large as Massachusetts, great forests of conifers in which are wild turkeys, the $500,000,000 spent to exterminate Indians. If anyone wishes more knowledge of New Mexico than can be gained by rolling through the state in a Pullman, he will find it attractively presented in Mr. Calvin's chapters.

HENSHAW WARD.

A Field Study of the Behavior and Social Relations of Howling Monkeys; by C. R. CARPENTER. Pp. 168, 16 pls. Baltimore (Johns Hopkins Press), 1934 ($2.25).—This number of the Comparative Psychology Monographs is the third of a series of naturalistic studies in primate habits planned to supplement the experimental studies in the Yale Laboratories of Comparative Psychobiology. The daily behavior of the clan, the consorts and the individuals of all ages is chronicled more completely than has been done for any of the other feral primates.—W. R. C.

Autumn Meeting of the National Academy of Sciences.—The autumn meeting of the Academy will be held in Cleveland at the Case School of Applied Science and Western Reserve University on November 19, 20, and 21, 1934. Luncheon for members and guests will be served at Wade Park Manor, as also a subscription dinner on Tuesday, November 20.

OBITUARY.

SIR EDGEWORTH DAVID, K.B.E., C.M.G.

Professor T. W. Edgeworth David, leading Australian scientist and dean of Australian geologists, died on August 28, 1934, at the age of 76. Born near Cardiff, Wales, and educated at Oxford, David went out in 1882 to join the Geological Survey of New South Wales. His first nine years there were spent mainly on the tin fields of New England and the Newcastle and Maitland coal areas. His more significant work, however, began with his appointment in 1891 to the chair of Geology and Physical Geography at the University of Sydney, where for thirty-three years he pursued a career which, as one of his students says, "left a great mark on the lives of many young Australian scientists."

In 1897, he put a core drill down to a depth of 1114 feet on the coral island of Funafuti, and the data so gained supported Darwin's subsidence theory of the origin of atolls. For this work, he was awarded in 1899 the Bigsby medal of the Geological Society of London, and a year later he was elected to the Royal Society. During the World War, although he was nearing sixty, he served as Chief Geologist for the British in France, winning rapid promotion to the rank of lieutenant-colonel. For this service he received the D.S.O., and two years later was knighted.

The writer met this tall, slender, deeply earnest professor in 1906, during the Tenth International Geological Congress in Mexico City, where he spoke on the glaciation in Australia during Cambrian and Permo-Carboniferous times. An animated, enthusiastic speaker, he forgot his time limit, but left an indelible impression. The following year David accompanied Shackleton to Antarctica to study an "ice age in being," helped to locate the South Magnetic Pole, and led the climbing party to the top of the ice-covered volcano Erebus (13,200 feet).

David's geological publications number over one hundred, but his most far-reaching one, the three volumes on the geology of his adopted and dearly beloved country, is still to come. In advance of this work he issued in 1932 a "New Geological Map of the Commonwealth of Australia," with 160 pages of "Explanatory Notes" (see this Journal, Oct., 1932, pp. 333-334), the closing words of which summed up the philosophy of this remarkable man: "To attain to absolute truth," he wrote, "we neither aspire nor desire, content, however faint and weary, to be still pursuing, for in the pursuit we find an exceeding great reward."

A few years ago, David announced the finding of fossils in Precambrian rocks, after a search lasting thirty years, and we are told that he wishes to be known for this discovery rather than for all the rest of his scientific work put together.

CHARLES SCHUCHERT.

OBITUARIES.

DR. JOHN HENRY BANKS, the New York geologist and metallurgist, died on October 3 at the age of seventy-three.

DR. WILLIAM HOLDING ECHOLS, professor of mathematics since 1891 at the University of Virginia, died on September 25 at the age of seventy-five.

DR. MAURICE FISHBERG, the Russian anthropologist, died on August 31 at the age of sixty-two.

DR. WILLIAM MITCHINSON HICKS, mathematician and physicist at Sheffield University, died on August 17 at the age of eighty-three.

DR. KARL FREDERIC KELLERMAN of the Bureau of Plant Industry, U. S. Department of Agriculture, died on August 20 at the age of fifty-four.

DR. BERTHOLD LAUFER, curator of anthropology at the Field Museum of Natural History, Chicago, died on September 13 when nearly sixty years old.

SIR THOMAS MUIR, the English mathematician, died on March 21 at the age of ninety-one.

DR. MARCUS SEYMOUR PEMBREY, professor of physiology at Greys Hospital, London, died on July 23 at the age of sixty-eight.

DR. ROBERT FRANCIS SCHARFF, the able Irish zoologist, died on September 11 at the age of seventy-six.

DR. FRANK L. STEVENS, professor of plant pathology at the University of Illinois, died on August 18 at the age of sixty.

PUBLICATIONS RECENTLY RECEIVED.

Elements of Modern Biology; by Charles R. Plunkett. New York, 1934 (Henry Holt and Co., $3.00).

Problems of Petroleum Geology; edited by W. E. Wrather and F. H. Lahee. Tulsa, Okla., and London, 1934 (The American Association of Petroleum Geologists, and Thomas Murby & Co., $6.00).

The Descent of the Atom (A Layman's Creation). Anonymous. Boston, 1934 (Lothrop, Lee and Shepard Co., $2.00).

Ergebnisse der exakten Naturwissenschaften. Band XIII. Berlin, 1934 (Julius Springer, final volume; RM. 28, gebunden RM. 29.40.).

Chan Kom a Maya Village; by Robert Redfield and Alfonso Villa R. (Carnegie Institution of Washington).

Sex and Culture; by J. D. Unwin. New York, 1934 (Oxford University Press, $12.00).

The Great Design. Order and Intelligence in Nature. Edited by Frances Mason. New York, 1934 (The Macmillan Co., $2.50).

Survey of India. Geodetic Report 1933. Published by Order of Brigadier H. J. Couchman, Surveyor General of India. Price 5 sh./3.

Les Lois fondamentales de l'Electricite; Deon Bouthillon and M. Goudonnet. Paris, 1934 (Gauthier Villars & Co., 25 fr.).

An Introduction to Quantum Theory; by G. Temple. New York, 1934 (D. Van Nostrand Co., $3.75).

U. S. Department of Commerce—Bureau of Mines: Mineral Resources of The United States 1931—Part I, Metals, II, Nonmetals; by O. E. Kiessling. Washington, 1934 (U. S. Government Printing Office, $1.50, Cloth).

AMERICAN JOURNAL OF SCIENCE

DECEMBER 1934

THERMALLY METAMORPHOSED DIORITE NEAR BROOKFIELD, CONNECTICUT

WILLIAM M. AGAR.

The town of Brookfield lies about six and one-half miles northeast of the center of the city of Danbury in western Connecticut. It is the locality from which the Brookfield diorite takes its name.

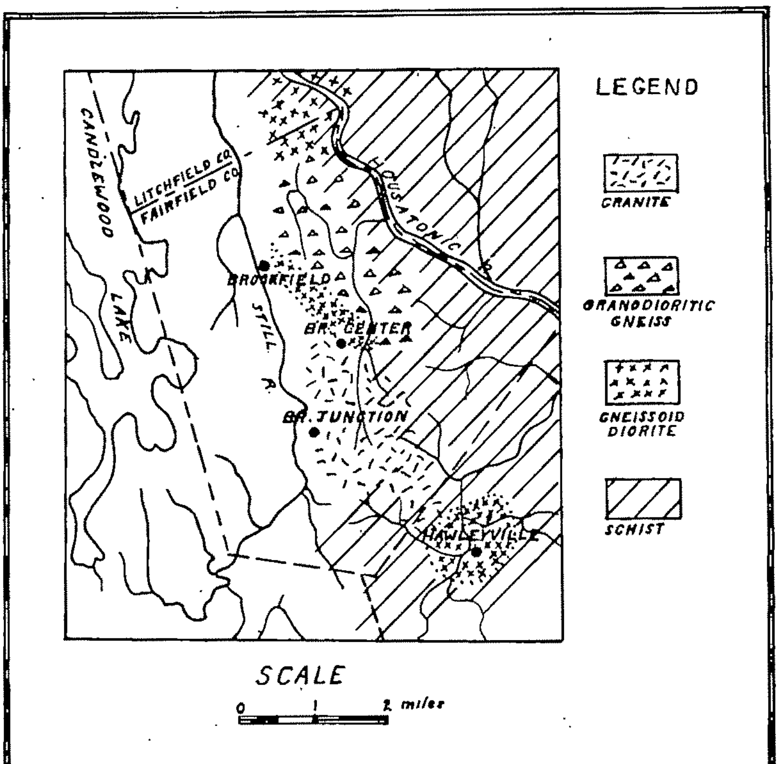
The Preliminary Geological Map of Connecticut[1] shows a long, narrow belt of this diorite extending south from the vicinity of Stillwater, across the Litchfield Co.-Fairfield Co. boundary, past Brookfield to Brookfield Center; and a smaller, irregular patch surrounding Hawleyville, three miles southeast. The western border of the northern patch is shown in contact with the Hartland schist, the eastern border with the Stockbridge limestone, the Poughquag quartzite, the Berkshire schist, and, at its southern extremity, with the Thomaston granite. The southern patch is intrusive into the Hartland schist and, on the west, into the older gneisses.

A reëxamination of the geology of the region confirms the general distribution of the rocks as indicated above, but with some notable exceptions. The Berkshire schist and the Poughquag quartzite do not occur in this region. Their place is occupied by interbedded quartz schists, quartz-mica schists, hornblende schists, and plagioclase-staurolite-cyanite schists which, together with the coarse, granite-injected biotite schists and gneisses compose the variable and widespread formation known as the Hartland schist.

Furthermore, much of the area between Brookfield Center and the county line to the north is not underlain by the Brookfield diorite but by a variable gneiss with the average composition of a granodiorite. This grades into the gneissoid Brookfield diorite on the north, about at the county line, and gives way to schist or granite on its other boundaries.

[1] Gregory, H. E., and Robinson, H. H.: accompanying Conn. Geol. and Nat. History Survey, Bull. 7, 1906.

The writer interprets this granodioritic gneiss as the result of alterations imposed upon the diorite by the younger granite magma. Diorite, thermally metamorphosed diorite, and both a quartz and a quartz-microcline injection phase are described. Tourmaline-bearing pegmatites cut the complex in several



places and sheared, pegmatitic granite previously[2] interpreted as a phase of the Thomaston granite gneiss occurs along its western border at Brookfield Junction.

The map (Fig. 1) accompanying this report indicates the general distribution of the rocks described. The Still River valley to the west is floored by marble, and farther west pre-Cambrian schists and granitic gneisses form the elevated land enclosing Candlewood Lake Basin. The area mapped pos-

[2] This Journal, p. 369, May, 1934.

sesses a very moderate relief and is notably poor in outcrops. Those that do occur are isolated from their neighbors by drift, meadow-land, or swamps. This fact, coupled with the apparent gradational character of all contacts makes their definite location impossible. The dotted lines, therefore, represent only approximate boundaries between types and the superposition of symbols is resorted to in order to indicate intimate penetration of schist by intrusives.

DESCRIPTION OF ROCK TYPES.

Brookfield Diorite.

This rock occurs in a number of other localities in western Connecticut and has been previously described.[3] It is composed of andesine, hornblende, variable quantities of biotite, and minor quartz. Apatite, titanite, and magnetite are constant accessories. Sericite, carbonate, and both epidote and clinozoisite form as alterations of the plagioclase. Granitoid textures and massive structures occur but gneissoid and even schistose phases are abundant. The latter are especially rich in biotite which then takes the place of some of the hornblende. Locally the rock is porphyritic.

The hornblende is usually dark green and strongly pleochroic, but light green, less pleochroic types occur. When the hornblende is dark and strongly pleochroic, it contains rods of black oxide and brown, platy, inclusions so disposed as to resemble the schiller structure of pyroxene. It may be that it has all been derived from pyroxene, all trace of which has vanished. But so complete a change during a late magmatic stage should be accompanied by more alteration of the plagioclase than is normally present in this rock, nor is the structure ordinarily such that the change can be ascribed to recrystallization under dynamothermal metamorphic conditions. The last paper listed under citation 3 (above) gives other reasons for concluding that the hornblende is primary.

The diorite in the region now under discussion has a gneissoid structure and is dominantly porphyritic with a mineralogy similar to that of the general type described. Its boundaries are gradational and mostly obscured by surface

[3] Rice and Gregory: Bull. 6, Conn. Geol. and Nat. Hist. Survey, pp. 107-108, 1906.
Agar, W. M.: Bull. 40, Conn. Geol. and Nat. Hist. Survey, pp. 28-31, 1927.
Agar, W. M.: this Journal, pp. 187-189, March, 1930.

cover. It has an elongate form roughly paralleling the folia-tion of the schists on the west but apparently cross-cutting those on the east. It intrudes the schist wherever contacts are visible and contains a number of xenoliths of both hornblende and biotite schist types.

At the southwestern extremity of the diorite, near the county line, diorite has intruded biotite schist both as stringers

Fig. 2. Rounded, irregular plagioclase phenocrysts surrounded by horn-blende and biotite with fluxional structure. "T" marks tourmaline replacing plagioclase.

Plane polarized light, x 20.

with cross-cutting relations and as layers parallel to the folia-tion. No noticeable reaction has taken place between the two, though some apatite and andesine have been added to the fine-grained schist layers. A single thin section may show the two types in contact. The type of reaction which could occur between the magma and this rock would be endo-thermic, since the minerals of the schist are later in the reac-tion series than those of the diorite, and would require a degree of superheat apparently lacking in the diorite magma. Quartz has been introduced into the complex but belongs to a

later phase closely related to the tourmaline-bearing pegmatites within one hundred feet of the rocks described.

Farther within the border of the diorite, about one-half mile west of Housatonic River along the county boundary line, a xenolith of hornblende gneiss occurs in the diorite. The xenolith is a fine-grained rock composed of aligned crystals of light green, slightly pleochroic hornblende set in a mosaic of oligoclase-andesine grains and accessory apatite. The plagioclase is usually clear but often encloses remnants of highly altered patches, either as cores of single crystals or as parts of several adjacent grains. These are evidently remnants of altered grains that did not quite clear up during the recrystallization of the rock, before it was torn from its base by the intrusion of diorite. Here again the diorite has had no chemical effect upon the inclusion which, in this case, has almost the same composition as the diorite.

The hornblende of this inclusion is indistinguishable from that in certain parts of the Brookfield diorite. Other parts of the diorite are rich in closely spaced bands of biotite and are consequently schistose. Along the southeast border of the mass, just across the Housatonic valley, the diorite is injected into schist in bands thick enough to be recognized in the field. These facts suggest that some of the schistose and finely foliated varieties of the Brookfield possess a structure inherited from the pre-existing schists, but that no actual assimilation of the schist has occurred.

On the other hand, the gneissoid structure of the diorite has a different origin. A fluxional arrangement of biotite and hornblende is usually quite marked. The plagioclase, particularly when it forms phenocrysts, is rounded, unfinished looking, and cracked (Fig. 2). Single phenocrysts are often divided into many irregular portions somewhat differently oriented with curved twinning lamellae, and the whole phenocryst has been partially rotated. The minor, interstitial quartz is clear and very slightly strained. These result in a protoclastic structure brought about by regional pressure during intrusion.

The total result is a rock with variable structural aspect but a fairly constant mineralogy throughout. Protoclastic quartz-diorite with minor biotite and a variable porphyritic tendency is the dominant type, but it includes schistose phases derived from hornblende or quartz-biotite schists by mechanical impregnation during a period of elevated temperature and regional stress.

The Granodioritic Gneiss.

The southern end of the long northern mass of diorite gneiss grades rather rapidly in the vicinity of the county line into a rock of totally different composition. Fig. 3 illustrates the first step in this change. The hornblende is the light green type and the gneiss may have had a mixed origin to begin with. Biotite is somewhat more plentiful than is normal and

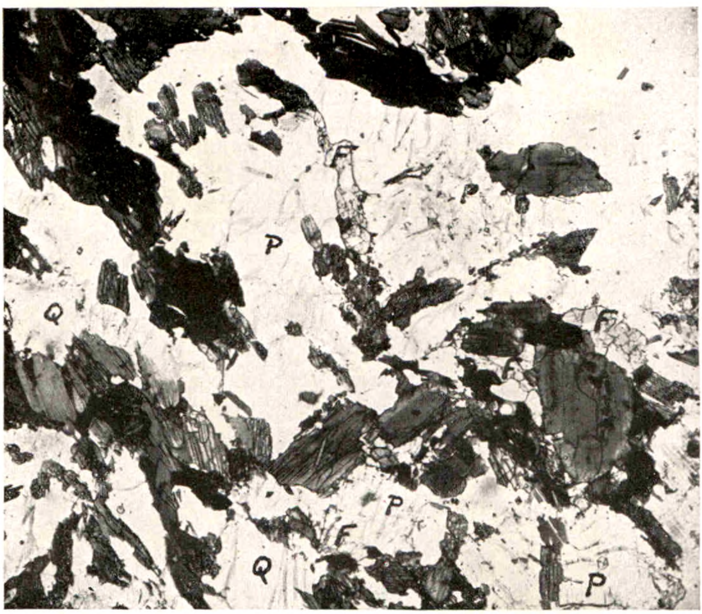


Fig. 3. Shows fluorite "F" introduced into the diorite gneiss. Biotite and epidote have replaced part of the hornblende. "P" is plagioclase, "Q" quartz.

Plane polarized light, x 20.

part of it at least is replacing the hornblende and is accompanied by granular epidote. The plagioclase is the andesine of the diorite unaltered save perhaps for some recrystallization. It is zoned and largely clear but contains sericitized patches that are unusually zonally arranged. Quartz has been introduced in lenticular patches with aligned inclusions of minute bubbles and some fluorite has been introduced though not so plentifully as Fig. 3 would indicate. This represents the first phase of thermal metamorphism of the diorite and is related

to the elevation of the regional temperature incident upon the intrusion of granite. Siliceous aqueous solutions carrying fluorine and boron permeated the diorite. Fig. 2 shows small amounts of tourmaline beginning to replace plagioclase in the protoclastic diorite gneiss which is otherwise unaffected by granitic emanations.

The next stage in the thermal metamorphism is marked by nearly complete alteration of hornblende to biotite and epidote, and a further clearing up of the andesine which is probably largely recrystallized. There is a great deal of titanite in this and most of the rocks still to be described. Much of it is undoubtedly the primary accessory titanite of the diorite partly granulated or even recrystallized. It may all have originated in this way but some is very finely granular and accompanies the biotite and epidote formed from hornblende. It has the appearance of having been formed from hornblende, though it is not known why biotite should reject the titanium.

Fluorite, some allanite, quartz, and very small amounts of alkali feldspar have been introduced into this type.

The next step shows all the hornblende altered to small flakes of biotite and epidote. These form bands that lie, together with small grains of sericitized andesine and larger somewhat more sodic and clearer plagioclase, between lenses of introduced quartz and large, clear, and nearly unstrained microcline crystals. One-half to one millimeter long crystals of allanite surrounded by epidote are sparsely distributed throughout. This is a thermally metamorphosed and injected gneiss with the composition of granodiorite.

Fig. 4 shows part of a thin section of a rock from near the center of this mass. A partially sericitized and epidotized, rounded andesine phenocryst with clear borders is surrounded by quartz and fine-grained microcline, and then by biotite, epidote, allanite, titanite, a little apatite, and minor amounts of muscovite that form very fine vermicular intergrowths with quartz. Occasional remnants of hornblende occur in the rocks of this area.

Farther to the south, and just east of Brookfield Center, the gneiss is composed of poorly zoned, partly sericitized and epidotized andesine, greenish brown biotite intergrown with epidote, titanite, allanite, and some apatite, microcline-microperthite, quartz, and muscovite. The muscovite forms vermicular intergrowths with plagioclase and the microcline penetrates the plagioclase and is itself embayed by a coarse

myrmekitic growth of quartz and sodic plagioclase. The plagioclase is partly altered to carbonate, epidote and sericite; biotite is slightly chloritized and titanite leucoxenized. This is a thermally metamorphosed and injected diorite gneiss that has been further affected by the late stage concentrations from the granite magma.

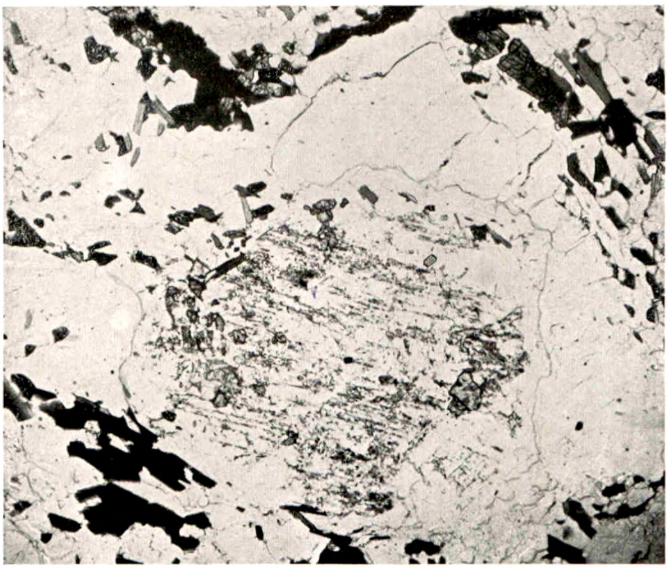


Fig. 4. Sericitized and epidotized plagioclase surrounded by quartz and microcline. Flaky biotite and epidote with fluxional structure surround the whole.

Plane polarized light, x 20.

The gneiss throughout this area tends to have a mortar structure. There has undoubtedly been some granulation, probably coincident with the emplacement of the granite, but much of the apparent granulation is due to replacement of the weakened borders of the andesine phenocrysts by quartz and microcline. Regional stress continued throughout the period of formation of this mixed, granodioritic gneiss as is evidenced by the sheared pegmatitic granite at Brookfield Junction.[4] The lack of important cataclastic effects in the intro-

[4] Op. cit., this Journal, p. 368, May, 1934.

duced microcline and quartz shows that the granite became rigid towards the end of its period of formation and further stresses were transmitted to the one zone of deformation. It is probable that the gneiss and the schists which it intrudes were thrust west over the border of the limestone.

The diorite gneiss around Hawleyville presents the same variable facies as elsewhere, but it is impossible to trace its contacts with the surrounding formations. Near the north end it is gneissoid and strongly porphyritic with andesine phenocrysts eight to nine millimeters long. Hornblende and biotite, which, together with epidote, is at least in part derived from hornblende, curve about the partly rotated and rounded plagioclase phenocrysts. Epidote also results from the alteration of the plagioclase and is accompanied by clinozoicite and sericite. There is much titanite and apatite in the rock and some pyrite which is largely oxidized. Quartz forms elongate pods or veins of medium sized grains and is the only material added to this gneissoid diorite.

The railroad just west of Hawleyville cuts through a variable gneiss that includes bands of quartz-mica schist and is itself cross cut by coarse pegmatite dikes. There are two varieties of gneiss here that appear to grade into one another. The first is composed of about 60% light and 40% dark minerals. The latter are biotite, minor residual hornblende, and considerable titanite and apatite which are intergrown with biotite and spread more or less throughout the other minerals. The light-colored minerals are plagioclase, microcline-microperthite, and very little quartz. The plagioclase is partly clear, unaltered oligoclase-andesine and partly a slightly more calcic type which is highly altered. This mineral is sericitized and full of well-formed crystals of epidote and clinozoicite. Biotite is partly chloritized and titanite leucoxenized.

The other type is a light colored rock with ten to twenty per cent of irregularly distributed femic minerals and fine-grained bands of the same materials that parallel the general foliation of the surrounding rocks. The microscope reveals the fine bands as composed of titanite, dark green hornblende, and rare flakes of biotite, in a fine mosaic of plagioclase and quartz. The large, irregularly distributed, dark patches are groups of poikiloblastic hornblende and granular titanite. Wherever biotite occurs in the hornblende, epidote is also present. These groups frequently cut across the fine bands

and are surrounded by oligoclase-andesine and quartz which also surround remnants of sericitized and epidotized plagioclase.

There are marked differences between these two rock types and the granodioritic gneiss described above. Titanite is common throughout, but it is much more plentiful here. The older plagioclase is more intensely altered and epidote and clinozoicite are both more common and in larger crystals.

The amount of titanite and epidote, and the late formation of poikiloblastic hornblende indicate a higher content of lime in the original rock. It is too completely recrystallized to be able to tell what was its original character, but the indications of a calcareous composition, and the included or interbedded quartz-biotite schists suggest original calcareous layers in the schist. If this is true, the granitic extracts reacted with the calcareous layers while the quartz-biotite schists were unaffected. Where the action was long continued and microcline was introduced in quantity, hornblende, formed at the height of igneous metamorphism, was partly made over into epidote and biotite and the latter to chlorite.

Pegmatite dikes cut the whole mass and grade into nearly pure alkali feldspar dikes that contain bunches of lustrous, deep green, fine-grained, chlorite, some muscovite and leucoxenized titanite. The pink feldspar penetrates the other minerals which are probably the last remnants of greatly altered schist inclusions. The chlorite has a peculiar birefringence which gives it a deep, purplish brown interference color. The pegmatites have not caused the metamorphism described above, but represent a differentiate from the granite magma which is responsible, and are themselves closely related in time to the final effects, such as the chloritization of the biotite.

The total effect of the granite magma upon the gneissoid diorite and the calcareous schists is to alter them to a composition as nearly like itself as possible. The reactions involved are exothermic and consequently require no superheat. They are similar to those taking place within a crystallizing magma during falling temperature and growing concentration of residual solutions. The mechanical effect of disintegration of the older rocks by the bodily injection of the granite minerals is also marked, but the merging of the two types is fairly complete and is in marked contrast to the purely mechanical effects of the diorite.

SUMMARY.

A diorite magma was intruded into hornblende and quartz-biotite schists during a period of regional stress. The mass of the diorite solidified with a protoclastic structure. Occasional schistose structures resulted from injections of diorite between layers of schist. The diorite lacked the superheat necessary to fuse and alter the intruded rocks, which either had a composition very similar to it and were essentially stable in its presence, or were composed of minerals later in the reaction series.

A later intrusion of granite thermally metamorphosed the diorite and then injected and reacted with it to form a gneiss of granodioritic composition. A rock of slightly different composition is attributed to similar action of the granite upon schist with a calcareous content higher than usual.

The granite intrusion was also accompanied by regional pressure which aided in the disintegration of the diorite and continued until after the consolidation of the magma had rendered the mass rigid. Further stresses were then transmitted to a zone along the western boundary of the area mapped and the pegmatites, which are elsewhere massive, were there crushed and granulated.

COLUMBIA UNIVERSITY,
NEW YORK CITY.

PALEONTOLOGY OF THE LITTLETON AREA, NEW HAMPSHIRE.*

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INTRODUCTION.

The Littleton area is located in the west-central part of New Hampshire. The district is of special geologic interest because of its fossil localities. These, although few in number, are of great importance to the geology of New England because they form a fossiliferous oasis in a large area of metamorphic and igneous rocks. They are the key to the historical geology of western New Hampshire. Despite this fact the stratigraphic and structural relationships of the rocks in the Littleton area had never been satisfactorily solved.

In an attempt to remedy this situation, the senior author spent the field seasons of 1931, 1932, and 1933 on the problem and has completed the mapping of the geology of the Moosilauke and Littleton (New Hampshire portion) quadrangles. In this work he has been very ably assisted by graduate students at Harvard University; for two seasons by Messrs. Jarvis B. Hadley and Charles B. Moke, for one season by Messrs. Randolph W. Chapman and William F. Jenks, and for part of one season by Messrs. Allen Waldo and Bartlett K. Thorogood. Without their patient help in the areal mapping the present results would be impossible. The junior author spent two weeks in the field, one in June, 1932, and the other in September of the same year. He is responsible for the paleontology, whereas the senior author is responsible for the areal mapping, stratigraphy, and structure. A brief note has already been published on the stratigraphy and paleontology of the area (1)† and a brief comment on the regional significance of our work has been presented (2). A brief description of the structure is found in another paper (3, pp. 148-150).

In addition to our own collection, which is now in the Museum of Comparative Zoölogy at Cambridge, Massa-

* Shaler Memorial Series, Publication Number 34.
† Numbers in parenthesis refer to bibliography at end of paper.

chusetts, the junior author has studied the Middle Silurian collection for Littleton in the U. S. National Museum. So far as we know this is the only other important existing collection of fossils from the locality. A few specimens at Dartmouth College and in the Boston Museum of Natural History were also examined.

We wish to take this opportunity to express our gratitude to the many friends who have aided this investigation. Professor P. E. Raymond has been very patient and helpful in discussing numerous problems concerning the identification of specimens and in criticizing the manuscript. Drs. Cooper, Ulrich, and Bassler were most courteous to the junior author during his visit to the U. S. National Museum, and Dr. G. A. Cooper, in particular, made valuable suggestions concerning the identification of several of the brachiopods. Miss M. Grace Wilmarth has very kindly discussed with us the names to be used for the various stratigraphic units and states that none of the formation names adopted have been used elsewhere.

The field work, on which this report is based, was financed in part by the Shaler Memorial Fund of Harvard University. The drafting was done by Edward A. Schmitz and the photographs were taken by F. P. Orchard.

STRATIGRAPHY.

The Littleton area contains pre-Silurian, Silurian, and Devonian strata. All the formational names are new with the exception of the "Littleton formation," for Hitchcock's (8, 9, and 10) units were lithologic rather than stratigraphic, and it has proved impossible to use them. In the present paper only a brief outline of the stratigraphy can be given, but the details will be presented by the senior author in a later paper.

The pre-Silurian rocks have been grouped into three formations: the *Albee quartzite*, *Ammonoosuc volcanics*, and *Partridge slate.* To date no fossils have been found in them but reconnaissance work by the senior author suggests that they may be younger than the fossiliferous Middle Ordovician of eastern Vermont (14), therefore, Upper Ordovician.

The Middle Paleozoic rocks have been divided into three formations: *Clough conglomerate*, *Fitch formation*, and *Littleton formation.* The *Clough conglomerate* is a very pure quartz conglomerate and quartzite which ranges in thickness

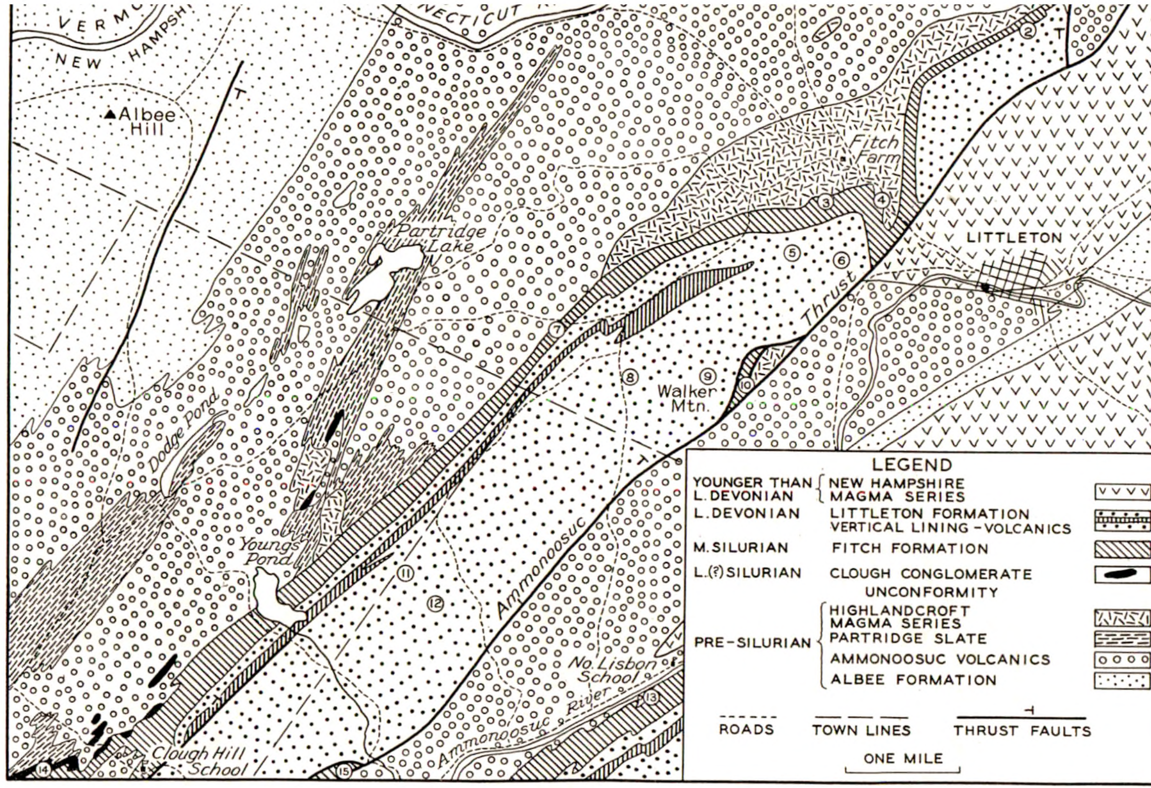

FIG. 1. Geologic map of the Littleton area, New Hampshire (part of Littleton and Moosilauke quadrangles). Areal geology by Marland Billings, assisted by Randolph W. Chapman, Jarvis B. Hadley, William F. Jenks, Charles B. Moke, Allen Waldo, and Bartlett K. Thorogood. Surveyed in 1931, 1932, and 1933. Numbers

from 0-200 feet. It is absent from most of the Littleton quadrangle due to overlap, but is well developed in the Moosilauke quadrangle (see Fig. 1). No fossils have been found in this formation, but since it is separated from the underlying rocks by a pronounced unconformity, and is transitional into the overlying Fitch formation, which is known to be Middle Silurian, we believe that the Clough conglomerate is Middle or Lower Silurian. The name is taken from the Clough Hill district, in the southwest corner of the area (Fig. 1).

The *Fitch formation*, northwest of the Ammonoosuc thrust (see Fig. 1) consists of limestone, calcareous slate, calcareous sandstone, arenaceous dolomite, arkose, and quartz conglomerate. In the belt which cuts across the southeast corner of the area, however, it is strongly metamorphosed, the calcite crystals being larger and such new minerals as biotite, diopside, andesine, and muscovite appearing. It ranges in thickness from 400 to 700 feet, and, as will be shown later, is of Middle Silurian age. The name is taken from the Fitch farm, two miles northwest of Littleton.

The *Littleton formation*, northwest of the Ammonoosuc thrust, consists of slate, sandstone, and volcanic rocks. In the area covered by the extreme southeastern corner of the map the rock is more severely metamorphosed, such new minerals as biotite, garnet (almandine), staurolite, and hornblende appearing. The formation is believed to be 5000 feet thick. On the basis of its fauna it is referred to the Oriskany (Lower Devonian). The name was proposed by C. P. Ross (15, p. 284).

PALEONTOLOGY OF THE FITCH FORMATION.

Fossils were first found in the Fitch formation, of Middle Silurian age, by C. H. Hitchcock in 1870 (6), apparently in some old quarries about two miles north of Littleton (locality 1 on Fig. 1). He submitted them to Elkanah Billings who identified them as Helderberg (6 and 8, vol. II, p. 339). In 1873 Hitchcock discovered the now famous locality at the Fitch farm and submitted his new collection to Billings, who this time stated that the rocks were "Upper Silurian" (our modern Silurian) or Lower Devonian (7, p. 476, and 8, vol. II, p. 340). In 1882 Hitchcock sent a collection to R. P. Whitfield who concluded that the strata were of "Middle Silurian" age, "probably Niagaran" (16).

In 1885 T. N. Dale collected material at the Fitch farm and in 1886 published a short list (5). In 1888 Pumpelly (13) published a list of species based on the material collected by Dale and identified by Walcott and Rominger. They assigned the strata to the Niagaran. In 1902 Hitchcock (9, p. 462) made a new collection from the Fitch farm and submitted the material to Schuchert, who prepared a new list, based in part on the new material and in part on the old material collected by Dale. Like most of his predecessors he concluded that the strata were Niagaran. Shortly thereafter, A. E. Lambert (9, pp. 480-482 and 10) proposed a new specific name for one of the trilobites, calling it *Dalmanites lunatus* (see pages 426-427 in this report). He concluded that the fossils "indicate a period in which the life of the Niagaran was passing over into that of a later period."

As will be shown later, we agree with most of our predecessors in assigning the Fitch formation to the Niagaran (Middle Silurian). In view of the fact that the specimens have never been described in detail or figured, we believe a careful discussion is justified.

The best faunule for the Fitch formation was found on the farm of G. E. Fitch, two miles west of Littleton. The fossil locality lies about one-third of a mile south of the house, and is designated as locality 3 on Fig. 1. The fossils are found in two beds, one a recrystallized limestone or marble, about twenty feet above the base of the formation, the other a calcareous slate—the "trilobite slate" of previous writers—about 40 feet above the base of the formation.

FAUNULE A. (Locality 3 of Fig. 1.)

Locality—The Fitch farm two miles northwest of Littleton. The classic collecting place is on top of a knoll surrounded by a growth of pine trees. The fossils occur in a recrystallized limestone and an overlying calcareous slate.

Limestone faunule—

Cup corals gen. et sp. ind.,
Favosites sp. ind. (two different species),
Halysites sp. ind.,
Stromatoporoid gen. et sp. ind.,
Crinoid columnals,
Conchidium nettlerothi Hall and Clarke,
Atrypa cf. A. reticularis (Linn.),
Spirifer sp. ind.

Calcareous slate faunule—

Bryozoa gen. et sp. ind.,
Strophonella funiculata (McCoy),
Leptaena rhomboidalis (Wilckens),
Pterinea cf. P. emacerata (Conrad),
Calymene sp. ind.,
Dalmanites limulurus Green.

The junior writer has examined the collection in the U. S. National Museum and compared the specimens in the list identified by Schuchert with those in our own collection. The identifications by the junior writer are practically identical although our list contains fewer specimens. For the sake of comparison the two lists are placed below:

Cleaves.	Schuchert.
Limestone.	
Cup corals,	
Favosites (two diff. species),	Favosites (two diff. species),
Halysites sp. ind.,	Halysites catenularia,
	Syringopora,
Stromatoporoid gen. et sp. ind.,	Stromatopora,
Crinoid columnals,	
Conchidium nettlerothi,*	Conchidium cf. knighti,
Atrypa cf. A. reticularis,	
Spirifer sp. ind.	
	Gastropod.
Calcareous slate.	
	Cup coral,
	Favosites,
Bryozoa gen. et sp. ind.,	
	Conchidium cf. knighti,
Strophonella funiculata,	Strophonella cf. funiculata,
Leptaena rhomboidalis,	Leptaena rhomboidalis,
	Rhynchonella (Wilsonia?),
	Atrypa reticularis?,
	Spirifer cf. sulcatus,
	S. plicatella or S. niagarensis,
Pterinea cf. P. emacerata,	Pterinea cf. emacerata,
Calymene sp. ind.,	Calymene tail,
Dalmanites limulurus.	Dalmanites cf. caudatus and limulurus (Walcott named it limulurus).

* C. nettlerothi is the same specimen as has been called C. knighti.

Earlier workers identified several species of *Favosites* from the limestone, but after an examination of a number of these forms (in the collections at Dartmouth and the Boston Museum of Natural History) we seriously question their specific identification. Although it is believed that more than one species is represented in our collection (massive and ramose forms), no reliable specific identification can be made. The specimens which we believe to be *Dalmanites limulurus* have been variously named from this locality. The difficulty has arisen from their distorted condition. After an examination of numerous examples it is believed that only one species is represented and that is the form generally recognized from this locality as *D. limulurus.*

A study of this formation as a whole reveals that in our collection there are but four diagnostic fossils from which to judge the age. These are *Conchidium nettlerothi*, *Strophonella funiculata*, *Pterinea* cf. *P. emacerata*, and *Dalmanites limulurus*. These are outstanding Middle Silurian (Niagaran) fossils. In addition to these the presence of *Favosites*, *Halysites*, *Leptaena*, *Atrypa*, and *Calymene*, in the same beds, is strong evidence of Middle Silurian age.

In addition to the faunule found at Fitch farm poorly preserved fossils have been found at seven other localities (Fig. 1: numbers 1, 4, 7, 10, 13, 14, and 15). At those localities, which are in the same structural belt as the Fitch farm locality (1, 4, 7, and 14) the fossils are *Favosites*, *Halysites*, cup corals, and crinoid columnals. In the discontinuous belt of the Fitch formation just northwest of the Ammonoosuc thrust (localities 10 and 15) only crinoid columnals have been found. At locality 13, near North Lisbon School, only crinoid columnals have been found, but their presence is rather remarkable for the rocks have been intricately crumpled. The strata have been intruded by a dike of amphibolite, and are now recrystallized to marble (in which crinoid columnals occur), mica schists, and a lime-silicate rock consisting of diopside, actinolite, andesine, and quartz.

PALEONTOLOGY OF THE LITTLETON FORMATION.

Lahee (11 and 12) was the first to discover fossils in the Littleton formation and concluded that the strata enclosing them were probably Lower Devonian. He found fossils at a number of isolated localities, but in most cases the material

was poorly preserved. From one locality, perhaps identical with our Tip Top Hill station (Fig. 1, locality 8), he identified four specimens. John M. Clarke, who examined the collection, said in a letter to Lahee, "I should hesitate to identify any single species among them, although they are to me conclusively early Devonian" (12, p. 249).

The best collecting in this formation is at Tip Top Hill. Here several hundred specimens were gathered. They were largely confined to a lens about ten feet long and six inches thick of medium-grained, gray sandstone. Evidently this represents a pocket into which the fossils were crowded, for extensive prospecting along the strike of this zone failed to reveal additional specimens. Since the exposed part of this bed had been removed, blasting must be resorted to if a larger collection is to be made.

Identification is rendered extremely difficult by shearing which has in many cases distorted and crushed the specimens. The danger of identifying species from such material is appreciated and the junior writer has hesitated to take such a step. However, it is believed that enough distinctive features of several characteristic forms are present to make specific identifications possible. Sufficient typical species are present to establish the Oriskany age of these beds.

FAUNULE B. (Locality 8 of Fig. 1.)

Locality—Tip Top Hill, approximately 100 yards southeast of the farm buildings across the road. The fossils occur in a gray sandstone immediately above a thin bed of slate.

Crinoid columnals,
Platyorthis circularis (Sowerby),
Leptostrophia magnifica (Hall),
Chonetes canadensis Billings,
Chonetes hitchcocki n. sp.,
? Schizophoria sp. ind.,
? Atrypa reticularis (Linnaeus),
Spirifer murchisoni Castlenau,
Leptocoelia sp. ind.,
Pterinea radialis Clarke,
Gastropod gen. et sp. ind.

FAUNULE C. (Locality 11 of Fig. 1.)

Locality—Mormon Hill, 6½ miles southwest of Littleton near Youngs Pond (Ogontz Lake). The fossils occur in interbedded

gray sandstone and black slate all along the western face of the hill. They may also be found in isolated outcrops in the fields lying to the west of the hill. Whereas the fossils at this locality are not as abundant as at Tip Top Hill they are more widely distributed.

Crinoid columnals,
Leptostrophia magnifica (Hall),
Schuchertella cf. S. becraftensis (Clarke),
Leptaena rhomboidalis (Wilckens),
Chonetes sp. ind.,
Spirifer murchisoni Castlenau,
Tentaculites schlotheimi Koken.

Very poorly preserved specimens have also been found at localities 2, 5, 9, and 12. Lahee (11 and 12) reported finding traces of fossils at locality 6, but we were not successful.

These faunules are of great importance because they provide a new geological landmark in the perplexing assemblage of sedimentary, igneous, and metamorphic rocks in New Hampshire. Hitherto the recognition of Devonian sediments has been conjectural and uncertain. In addition they permit correlation with fossil-bearing sandstones in northern Maine which have long been established as of Oriskany age. These sandstones are in the Moose River formation and are found in the region around Moosehead Lake (4 and 17).

The bulk of the Littleton fauna consists of brachiopods, the large numbers of pelecypods and gastropods known from the Moose River formation being absent. However, most of the Littleton fossils thus far found are represented in that formation, by identical or related forms. The striking similarity to the Grand Grêve formation in Quebec, and the New York Oriskany is also an important feature, as is illustrated in the table below.

The evidence shown in the table indicates a very close relationship of the Littleton fauna with those of the Grand Grêve, Moose River, and New York Oriskany faunas. There is little doubt but that most of these formations are of the same age. The Dalhousie, generally recognized as of Helderberg age, contains only three of the Littleton forms and since these are all long-range types they have no significance. The Chapman sandstone of Maine, which is considered to be slightly older than the Moose River sandstone (17, p. 12), contains four typical Littleton fossils of which one is long range. If

Table Showing Age Distribution of Littleton (Devonian) Fossils in Maine, Quebec, and New York.

	D	GG	MR	C	NY
Platyorthis circularis		o			o
Leptostrophia magnifica		x	x	o	x
Schuchertella cf. S. becraftensis		x			x
Leptaena rhomboidalis	x	x		x	x
Chonetes canadensis		x	x		
C. hitchcocki n. sp.			x		
C. sp. ind.					
?Schizophoria	x	x			
?Atrypa reticularis	x		x		
Spirifer murchisoni		x	x		x
Leptocoelia		o	o		o
Pterinea radialis			x	x	
Gastropod gen. et sp. ind.					
Tentaculites schlotheimi			x	x	

Legend:

x Same species. o Related form.

D—Dalhousie, GG—Grand Grêve, MR—Moose River, C—Chapman, NY—New York Oriskany.

Summary of table:

	D	GG	MR	C	NY
Number of Littleton fossils in other formations	3	8	8	4	6
Of these there are the following long-range forms	3	3	2	1	2

this formation is considered to be slightly younger than the Helderberg and a little older than the Oriskany it is quite conceivable that a number of forerunners of the Oriskany fauna might be present.

A comparison of the Littleton fauna with the typical Oriskany fossils of New York reveals that the specimens in the former formation are generally smaller. Although one is impressed by the Oriskany aspect of the Littleton fauna, a critical examination of the material shows, in some instances, slight variations. This does not seem illogical if the conditions of the environment in New Hampshire were somewhat different from those which obtained during the deposition of the Oriskany strata in New York and Pennsylvania. The strata may possibly be a little older, and the fossils less highly developed than those a few hundred miles to the west and south. It appears from Dr. Clarke's descriptions, that such common fossils as *Rensselaria* and *Hipparionyx* are represented in Gaspé and Maine by smaller individuals than those in New York. It is probable that ecological factors, such as,

for instance, the amount of available food, may enter into the explanation of these differences.

Reference to the geologic map (Fig. 1) shows that the two localities, 8 and 11, at which diagnostic fossils have been found lie about 2500 to 3000 feet southeast of the line which shows the position of the base of the Littleton formation. The strata are essentially vertical and in so far as we can learn, there is no evidence of repetition by folding; for example, the sharp angles shown in the contacts of the volcanic member of the Littleton formation northwest of locality 11 and north of locality 8 are sedimentary, not structural features. The two good fossiliferous zones are, therefore, from 2500 to 3000 feet above the base of the Littleton formation. Strictly speaking, therefore, we can only say that the middle part of the Littleton formation has been demonstrated to be of the same age as the Moose River and the Oriskany. It is possible that the lower portion is older than the Oriskany and that the upper portion is younger. The few poorly preserved specimens found near the base of the formation—locality 2—and in the upper portion—locality 9—as far as we can judge do not differ greatly from the Oriskany forms of localities 8 and 11.

Descriptive Paleontology.

SILURIAN FOSSILS.

Coelenterata

Cup corals, gen. et sp. ind.

Simple conical corals becoming conico-cylindrical in some of the larger specimens. The septa show up well on the exteriors of the specimens, but recrystallization has destroyed all trace of the internal structure. The specimens found at Fitch Farm (locality 3) are very small whereas those found at locality 14 are of moderate size.

Locality: Fitch Farm; (locality 3), ¾ mile W Clough Hill School (loc. 14).

Museum Comp. Zoölogy, No. 9316.

Favosites sp. ind.

Two different types (massive and ramose) of *Favosites* were collected, but so much of the detail of the corallites is

obscure that no specific determinations may be safely made. Some specimens consist of hemispherical heads, others, although massive, possess no definite shape, having been crushed during the metamorphism of the rock. In no specimen is the preservation good enough to show mural pores although in one (M. C. Z., no. 9317) closely spaced tabulae are seen.

Locality: Fitch Farm (loc. 3); ½ mile NW Parker Mountain (loc. 1); ½ mile E Slate Ledge School (loc. 7); ¾ mile W Clough Hill School (loc. 14).

Museum Comp. Zoölogy, Nos. 9317, 9318.

Halysites sp. ind.

Although several specimens of *Halysites* were collected, in no case is the preservation sufficiently good to permit specific identifications. One specimen, however, does show closely spaced and well developed tabulae. The coralla are composed of cylindrical, compressed corallites joined in intersecting and branching laminae. The latter consist of rows of corallites united along the whole of their adjoining sides.

Locality: Fitch Farm (loc. 3); 1¼ miles NW Littleton on the St. Johnsbury Road (loc. 4).

Museum Comp. Zoölogy, No. 9319.

Stromatoporoid gen. et sp. ind.

The single specimen of a stromatoporoid obtained does not show sufficiently detailed structure to identify the genus or species. It is small and globular; a polished section shows concentric laminations. Thin sections show the laminae and indistinct, continuous radial pillars. Specimens in the National Museum show larger and better defined expansive types, with astrorhizae and radial canals.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, No. 9321.

Bryozoa gen. et sp. ind.

The one fragmentary specimen in the collection resembles a fenestellid type of bryozoan. It shows a reticulated expansion of slender, frequently bifurcating branches, which are

united by thin dissepiments. The fenestrules are elongate-oval, but their shape is accentuated by distortion. No apertures were observed.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, No. 8708.

Brachiopoda.

Strophonella funiculata (McCoy).

Plate II, Fig. 10.

McCoy, F.: Synopsis of the Silurian fossils of Ireland, p. 30, plate III, fig. 11, 1846.

Bastin, E. S., and Williams, H. S.: Eastport Folio, U. S. Geol. Survey No. 192, p. 6, 1914.

This species is represented by two specimens, both small and somewhat distorted. The hinge-line is straight and extended; outline subquadrate; surface multicostellate. Striae narrow and deep; costellae show a central groove increasing in strength toward the front. One specimen shows the anterior commissure faintly uniplicate, but this is misleading and was apparently caused by the metamorphism of the rock. The other specimen is drawn out laterally as are specimens in the U. S. National Museum. The outline of the figured specimen is doubtless due to the crushing of the rock. The cardinal angles are subauriculate, and the specimens are geniculate.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, No. 8660.

Conchidium nettlerothi Hall and Clarke.

Plate II, Figs, 8, 9.

Hall and Clarke: Paleontology of New York; Vol. 8, pt. 2, p. 234, 1893.

Two specimens of this species were collected. The shells are subtriangular in outline with a very short hinge-line. One specimen (plate II, fig. 9) is that of a small dorsal valve, and the other (plate II, fig. 8) a ventral valve. Both valves are strongly convex, but the dorsal valve has the greater convexity. Commissure not seen in the dorsal, but is rectimarginate in the ventral valve. Narrow, shallow, and straight sulcus in the dorsal valve. No fold observed in the ventral valve; shell structure partly worn away showing position of

median septum. Umbo swollen; shell multicostate. No details of the interior may be seen. This is the *Pentamerus knighti* of Nettleroth.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, Nos. 8655, 8656.

Leptaena rhomboidalis (Wilckens).

Hall and Clarke: Paleontology of New York; Vol. 8, pt. 1, p. 279, pl. 8, figs. 17-19, 1892.

This is a small specimen, roughly semicircular in outline. The costellae are thin and flexuous, about equal in width to the interspaces, multicostellate. The transverse wrinkles on the surface of the shell are especially strong on the lateral portions.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, No. 8665.

Atrypa cf. A. reticularis (Linnaeus).

Hall, J.: Paleontology of New York; Vol. 2, pp. 72-73, pl. 13, figs. 8a-e, 1852.

Two specimens of this form were collected, one from the calcareous slate and one from the limestone. Both have been severely crushed.

Shell subcircular, moderately convex, multicostellate; costellae bifurcate near anterior margin. They are left faintly nodose by the crossing of elevated lines of growth. Each is believed to be a dorsal valve.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, Nos. 8657, 8658.

Spirifer sp. ind.

Only one small, distorted *Spirifer* was collected. It is a dorsal valve on which there is a high fold and three strong costae beside it. The length of the hinge-line and the nature of the cardinal extremities is not known because of the fragmentary condition of the specimen. No detailed surface ornamentation is present. This may be the *Spirifer* cf. *sulcatus* identified from this locality by Schuchert.

Locality: Fitch Farm (loc. 3).

Museum Comp. Zoölogy, No. 8659.

Mollusca.

(Pelecypoda).

Pterinea cf. P. emacerata (Conrad).

Plate II, Fig. 15.

Hall, J.: Natural History of New York, Part IV, Geology (4th district), pp. 108 and 109, 1843.
Hall, J.: Paleontology of New York; Vol. 2, p. 83, pl. 27, 1852.

This species is represented by one fairly well preserved specimen and several badly distorted ones. The outline is semi-elliptical, valve slightly convex, longer than high. Surface ornamented by fine elevated radiating lines, which diverge toward the margin and are crossed by fine concentric lines which give the surface a faintly cancellated appearance. Anterior wing obscure, posterior wing partly broken away, but well enough preserved to show the presence of radiating and concentric lines upon it.

Locality: Fitch Farm (loc. 3).
Museum Comp. Zoölogy, No. 1855.

Arthropoda.

Trilobita.

Calymene sp. ind.

The only specimen found is a fragmentary cephalon showing a convex, globular glabella. Two pairs of glabellar furrows and three glabellar lobes are present. The latter are seen on the right side only and the first is faint. Fracturing of the specimen has destroyed other parts.

Locality: Fitch Farm (loc. 3).
Museum Comp. Zoölogy, No. 1855.

Dalmanites limulurus Green.

Plate II, Figs. 11-14.

Dalmanites limulurus. Green, J.: Monograph on the Trilobites of North America; p. 48, 1832.
Hall, J.: Paleontology of New York; Vol. 4, p. 101, figs. 1-2, 1843.
Dalmanites lunatus. Lambert, A. E.: Geol. Soc. Amer., Bull. Vol. 15, pp. 480-482, 1904.

A large number of fragments of this species has been collected. Two show most of the cephalic shield, several others portions of free-cheeks with genal spines, and twelve show entire or fragmentary pygidia. The glabella is pustulose and the frontal margin of the cephalon is lingulate.

These specimens appear to be identical with those described

as *Dalmanites lunatus* by Lambert. There is little doubt of their being the same species, but so far as the writer can see, there is no reason why they cannot be identified as *Dalmanites limulurus* Green. The cephalic shield also shows the presence of cephalic denticulations, which were said to be absent by Lambert. A comparison with specimens of *D. limulurus* in the Museum of Comp. Zoölogy shows that the nature of these denticulations varies considerably, some specimens lacking them.

Lambert established his species upon the lunate shape of the cephalic shield and its proportions. This is believed by the junior writer to be inadvisable, inasmuch as the original proportions have been destroyed during the shearing of the rocks in which the specimens are found. He also cited as characteristic the great anterior breadth of the pygidia and the shortness and acutely triangular nature of the pygidial spine. Several specimens in this collection show such features but others exhibit the normal type of pygidium and pygidial spine found in *D. limulurus*. The specimens showing abnormalities of breadth of pygidium and shortness of spine have obviously been distorted by the crushing of the rock.

The number of annulations in the axial lobe and the number of ribs of the pygidium are usually 12, and 7 or 8 respectively, as in *D. limulurus*. The ribs are furrowed in the same way. The anterior glabellar lobe extends obliquely forward.

In view of the above facts this trilobite is identified as *Dalmanites limulurus*, and *Dalmanites lunatus* is believed to be a synonym having been mistakenly established as a new species.

Locality: Fitch Farm (loc. 3)

Museum Comp. Zoölogy, Nos. 1856, 1857, 1858, 1859.

DEVONIAN FOSSILS.

Brachiopoda.

Platyorthis circularis (Sowerby).

Plate I, Figs. 2, 3, 6.

Schuchert and Cooper: Brachiopod Genera of the Orthoides and Pentameroidea; Peabody Museum Natural History, Mem. Vol. IV, pt. 1, p. 135, pl. 19, figs. 27-27, 1932.

This species is represented by six specimens, all relatively small ventral valves. Four of them are fragmentary but the two complete ones measure, in length and breadth, 24 and 25

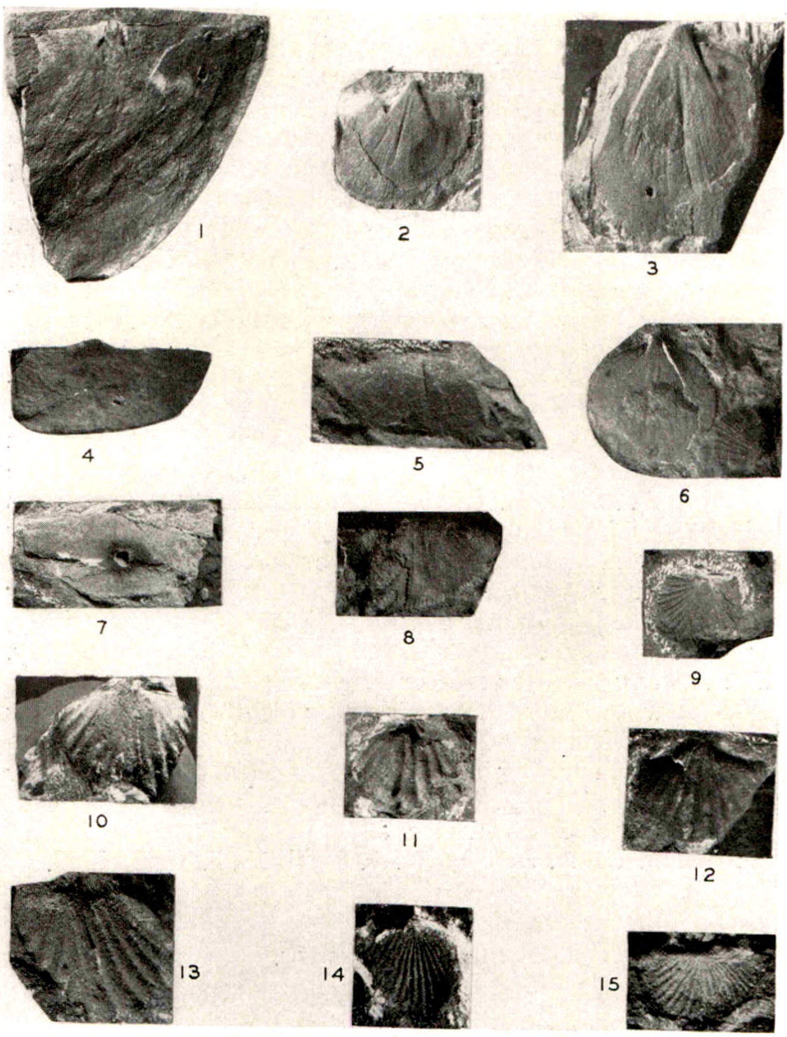

Plate I. Lower Devonian Fossils.

millimeters, and 23 and 24 millimeters. The largest specimen is 40 millimeters long. The outline is subcircular, the greatest width being at the mid-length. The valves are moderately convex. Ventral umbo swollen, hinge-line short. The surface is multicostellate, fibrous, with neither fold nor sulcus. On the internal cast, the costellae are commonly represented by a narrow fringe around the margin. The muscle field is large, flabellate, occupying more than half of the interior; diductor scars elongate, divided by median ridge on a slight expansion of which are borne small elongate adductor scars. The muscle area is bounded by strong lamellae which diverge at an acute angle.

This shell should not be confused with *Hipparionyx unguiformis* (a nomen nudum) or *Hipparionyx minor* Clarke, both listed from the Chapman sandstone of Maine. Unlike

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PLATE I.

Figure 1. *Leptostrophia magnifica* (Hall).
Figures 2, 3, 6. *Platyorthis circularis* (Sowerby).
Figures 4, 5, 7, 8. *Chonetes canadensis* Billings.
Figure 9. *Schuchertella* cf. *S. becraftensis* (Clarke).
Figures 10-13. *Leptocoelia* sp. ind.
Figure 14. *Chonetes* sp. ind.
Figure 15. *Chonetes hitchcocki* n. sp.

1. *Leptostrophia magnifica* (Hall). × ¾. A ventral valve showing wrinkles, the faint outline of the broad muscle-area, and the strongly pitted area between the muscle scars and the hinge-line. Littleton formation.

2, 3, 6. *Platyorthis circularis* (Sowerby). × ¾. Three typical ventral valves showing the strong, flabellate muscle-scars, and the small abductors on the ridge along the median line. Figure 6 also shows a *Pterinea radialis* on the same block. Littleton formation.

4, 5, 7, 8. *Chonetes canadensis* Billings. × ¾. Four specimens illustrating the large size of this species. Figures 5, 8, show the characteristic fringe on the anterior margins of the cast; they also show the presence of the mid-rib. Littleton formation.

9. *Schuchertella* cf. *S. becraftensis* (Clarke). × ¾. Internal mold showing small size, nearly square outline, and multicostellate surface. Littleton formation.

10, 12. *Leptocoelia* sp. ind. × 1½. Specimens of ventral valves showing the high, strongly elevated musculature, and the 5 or 6 rounded costae on either side of the narrow sulcus. Littleton formation.

11, 13. *Leptocoelia* sp. ind. × 1½. Molds of dorsal valves showing the position of crural bases. Littleton formation.

14. *Chonetes* sp. ind. × 1½. Small ventral valve showing multicostellate surface and nearly square outline. Littleton formation.

15. *Chonetes hitchcocki* n. sp. × 1½. Small shell showing straight hinge-line, coarse multicostellate surface, and extended cardinal extremities. Littleton formation.

these forms, *Platyorthis circularis* has no short umbonal septum, no strongly impressed median adductor scars, or acutely diverging dental lamellae. The dental plates diverge widely and are produced forward as sharp ridges along the lateral margins of the diductor scars. It is not known definitely whether or not *Platyorthis* is punctate, although wax squeezes suggest a coarse punctosity. The shelly structure is, however, so recrystallized and the material of the cast so coarse this feature is in doubt.

Locality: Tip Top Hill (loc. 8).

Museum Comp. Zoölogy, Nos. 8666, 8667, 8668, 8669.

Schuchertella cf. S. becraftensis (Clarke).

Plate I, Fig. 9.

Clarke, J. M.: New York State Museum, Mem. Vol. III, No. 3, p. 51, 1900.

Shell small, suborbicular, nearly square in outline, with prominent sharp costellae increasing by implantation. The hinge-line is straight, shorter than the greatest width of the shell which is about half way between the hinge-line and the anterior margin. The specimen is 17 millimeters wide and 14 millimeters long. The umbo is fairly high and slopes with low convexity toward the margins. The dental lamellae diverge at an angle of 115°. The material composing the cast is coarse, and the metamorphism the rock has undergone has obscured much of the finer surface detail.

Locality: Mormon Hill (loc. 11).

Museum Comp. Zoölogy, No. 8670.

Leptostrophia magnifica (Hall).

Plate I, Fig. 1.

Hall, J.: Paleontology of New York; Vol. 3, pp. 414, 482, 1859.

About half a dozen specimens of this species were collected, all in a more or less fragmentary condition. The shell is wider than long, although a few specimens are nearly equidimensional. Front of shell arcuate, curving gently into the rounded sides. Cardinal angles rectangular to subauriculate. Maximum elevation of the shell in the pedicle valve over the muscle area, a varying distance behind the middle. Muscle-scars of the pedicle valve subtriangular, spreading from the beak, divided into at least four lobes on either side of the median line, and extending about two-thirds of the way to the

front of the shell. The margins of the muscle-scars diverge in an acute angle which varies slightly in different specimens. Strong pitting is observed in one specimen in the area between the margin of the muscle-scars and the hinge-line. The pitting becomes less conspicuous toward the hinge-line; other details of the interior are obscure.

The surface is ornamented by fine, distinct, radiating costellae approximately uniform in size and strength. They are rounded or subtriangular, and straight or slightly flexuous. They increase by implantation and in typical forms about 14 occur in a space of 5 millimeters. There are no small, oblique wrinkles in the area of the cardinal angles, as sometimes occur in typical specimens, but the triangular pit in the narrow, posterior part of the muscle area is present.

The shells vary slightly in size, but average about 60 millimeters in width along the hinge-line, and about 45 millimeters in length. These figures show the New Hampshire specimens to be generally smaller than the otherwise similar, typical New York specimens.

Locality: Tip Top Hill (loc. 8) and Mormon Hill (loc. 11).

Museum Comp. Zoölogy, Nos. 8671, 8672.

Leptaena rhomboidalis (Wilckens).

Williams, H. S., and Breger, C. L.: Fauna of the Chapman Sandstone, Maine; U. S. Geol. Survey, Prof. Paper 89, pp. 32-33, 1916.

Shell roughly semicircular, greatest width along the hinge. Costellae thin and flexuous, about equal in width to the interspaces; the wrinkles on the surface of the shell are especially strong on the anterior portion. The specimen collected is small, about 12 millimeters wide and 11.5 millimeters long; it is slightly distorted.

Locality: Mormon Hill (loc. 11).

Museum Comp. Zoölogy, No. 8673.

Chonetes canadensis Billings.

Plate I, Figs. 4, 5, 7, 8.

Billings, E.: Paleozoic Fossils of Canada; Vol. 2, pt. 1, p. 17, fig. 7, 1874.

This is a large, nearly flat *Chonetes*, transversely extended, semi-elliptical in outline, and covered with radiating costellae of which there are 12-18 in the space of 5 millimeters near the anterior margin of a typical specimen. A median rib is present on some specimens. The hinge-line is commonly equal

to the greatest width of the shell. The width and length of three typical specimens are respectively: 35 and 17 millimeters, 36 and 17 millimeters, and 34 and 14 millimeters. The lateral margins vary in their relationship to the hinge-line. In some they are roughly perpendicular to it, whereas in others they curve gently up to it. The anterior margin is a broad flat arch. The pedicle valve is depressed-convex; the brachial valve slightly concave, the shell structure pitted, multicostellate.

Locality: Tip Top Hill (loc. 8).

Museum Comp. Zoölogy, Nos. 8674, 8675, 8676, 8677.

Chonetes hitchcocki n. sp.

Plate I, Fig. 15.

This is a coarsely ornamented *Chonetes* with a small shell and a transversely rectangular outline. The one well preserved specimen is 10 millimeters wide and 5 millimeters long. The greatest convexity is in the middle; cardinal angles flattened; commissure arcuate; hinge-line equal to the greatest width.

The surface is ornamented by about twenty coarse costellae with increase by implantation and bifurcation. Interspaces as wide or wider than the costellae except in the umbonal region. The cardinal spines are not preserved.

This specimen seems to be identical with that identified by Williams and Breger as *Chonetes vicinus var. deflecta* Hall from the Moose River sandstone in Maine. A comparison with *C. deflecta* Hall, however, shows that the Littleton form has far fewer and coarser costellae. Furthermore the Littleton specimen measures, length to width as 1 to 2, rather than 4 to 5, or 8 to 9, as in *C. deflecta*. *Chonetes vicinus* is considered as identical with *C. deflecta* by Prosser and Kindle in their report published by the Geological Survey of Maryland. Examination of *C. vicinus* shows it to have a larger number of costellae and a more nearly square outline than the New Hampshire form.

Chonetes hitchcocki resembles *C. jerseyensis* more closely than any other Chonetes, yet differs from it in having fewer costellae which do not show a slight anterior curvature as they approach the margin. In addition the proportions of the former are length to width, as 1 to 2, instead of 7 to 11. In view of these differences the New Hampshire specimen is made a new species and attention is called to the fact that this

shell is doubtless the same as that called *C. vicinus var. deflecta* Hall by H. S. Williams and C. H. Breger (17, p. 49).
Locality: Tip Top Hill (loc. 8).
Museum Comp. Zoölogy, No. 8678.

Chonetes sp. ind.

Plate I, Fig. 14.

Shell small, about 12 millimeters in width, moderately convex, with distinct costellae, about 14 in number. Valve slightly longer than wide.
Locality: Tip Top Hill (loc. 8).
Museum Comp. Zoölogy, No. 8679.

? *Schizophoria* sp. ind.

Shell of small size, plano-convex; outline ovate; about twice as long as wide; 13 costellae in about 5 millimeters. Multicostellate. The costellae curve backward strongly near the posterior margin.
Locality: Tip Top Hill (loc. 8).
Museum Comp. Zoölogy, No. 8680. (Gastropod on same specimen.)

? *Atrypa reticularis* (Linnaeus).

Hall, J.: Paleontology of New York; Vol. 2, pp. 72-73, pl. 23, figs. 8a-e, 1852.

Shell with coarse radiating costae; muscle-scars prominent. The one specimen collected has been crushed and severely distorted.
Locality: Tip Top Hill (loc. 8).
Museum Comp. Zoölogy, No. 8681.

Spirifer murchisoni Castlenau.

Plate II, Figs. 1-4.

Williams, H. S., and Breger, C. H.: Fauna of the Chapman Sandstone, Maine; U. S. Geol. Survey, Prof. Paper 89, pp. 95-103, 1916.

This *Spirifer* is the most common brachiopod in the Littleton formation and many specimens were collected. It is of medium size, with 6 to 8 strong, rounded to subangular costae on either side of the simple sulcus and fold. The outline is transversely extended, the hinge-line equal to the greatest

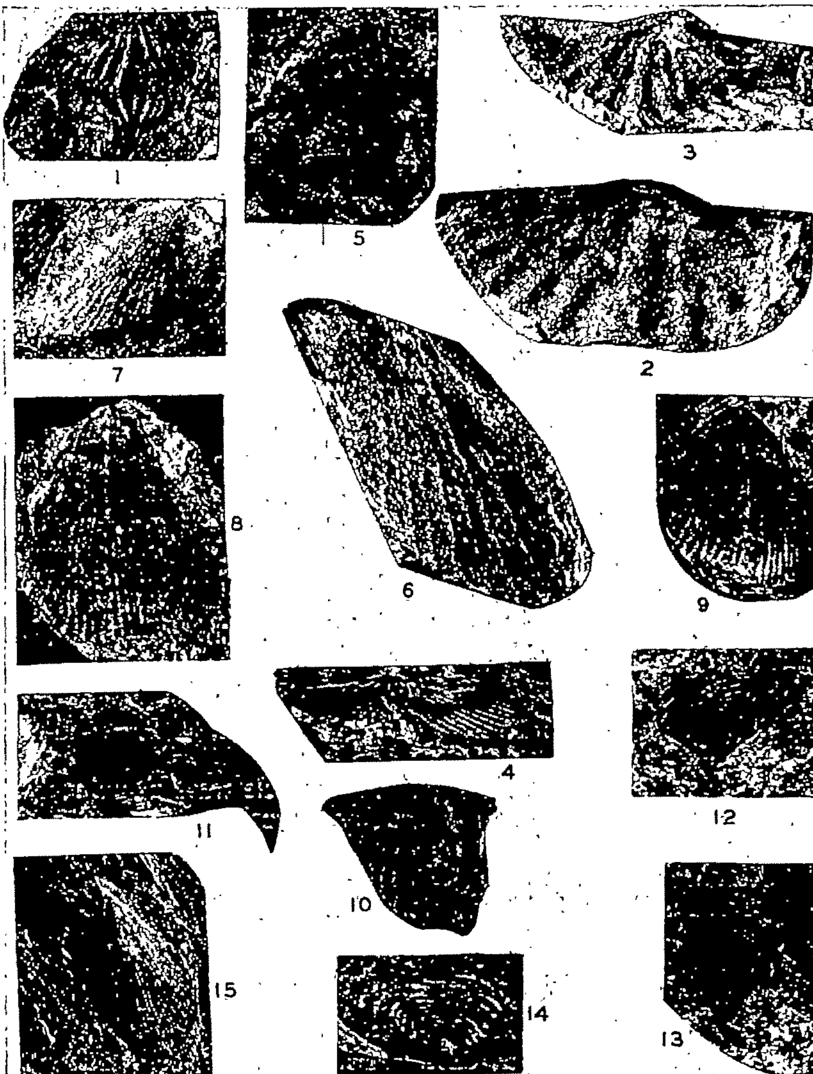

PLATE II. Lower Devonian and Middle Silurian Fossils.

width of the shell. The cardinal extremities are rectangular, and the width of the valves slightly more than twice the length. The costae are wider than the interspaces, and the outer ones are obsolescent. No finer surface ornamentation is visible.

Both ventral and dorsal valves are present. The former is more gibbous than the latter and possesses the strongly elevated muscle area so characteristic of this species. The dorsal valve is slightly convex near the middle and the mesal fold is well rounded and more than twice as wide as any of the costae.

Locality: Tip Top Hill (loc. 8) and Mormon Hill (loc. 11).

Museum Comp. Zoölogy, Nos. 8661, 8662, 8663, 8664, 8665.

PLATE II.

Figures 1-4. *Spirifer murchisoni* Castlenau.
Figures 5-7. *Pterinea radialis* Clarke.
Figures 8, 9. *Conchidium nettlerothi* Hall and Clarke.
Figure 10. *Strophonella funiculata* (McCoy).
Figures 11-14. *Dalmanites limulurus* Green.
Figure 15. *Pterinea* cf. *P. emacerata* (Conrad).

1, 2. *Spirifer murchisoni* Castlenau. (Figure 1, × ¾; Figure 2, × 1½). Internal molds of ventral valves showing strong, simple costae and high muscle area. Littleton formation.

3, 4. *Spirifer murchisoni* Castlenau. (Figure 3, × 1½; Figure 4, × ¾). Internal molds of dorsal valves showing characteristic hinge-features. Littleton formation.

5, 6. *Pterinea radialis* Clarke. × 1½. Molds of left valves showing both concentric and radial surface markings. Littleton formation.

7. *Pterinea radialis* Clarke. × 1½. Mold of right valve showing radial surface markings, a poorly defined anterior wing and a portion of the posterior wing. Littleton formation.

8. *Conchidium nettlerothi* Hall and Clarke. × ¾. A ventral valve, rectimarginate, multicostate, showing median septum. Fitch formation.

9. *Conchidium nettlerothi* Hall and Clarke. × ¾. A dorsal valve strongly convex, with narrow, shallow sulcus. Fitch formation.

10. *Strophonella funiculata* (McCoy). × 1½. Small shell with flattened, grooved costellae, slightly geniculate. Fitch formation.

11. *Dalmanites limulurus* Green. × ¾. Cephalon, showing expanded glabella, glabella furrows and lobes, and genal spine. Fitch formation.

12-14. *Dalmanites limulurus* Green. × 1½. Pygidia showing rachis with annulations, furrowed pleural ribs, and terminal spine. Fitch formation.

15. *Pterinea* cf. *P. emacerata* (Conrad). × ¾. Mold of left valve showing concentric and radial surface markings, small posterior wing and indistinct anterior wing. Fitch formation.

Leptocoelia sp. ind.

Plate I, Figs. 10-13.

Hall, J.: Paleontology of New York; Vol. 3, p. 450, 1859.

This is a small shell in which the width is slightly greater than the length. There are from four to six strongly elevated, well-rounded costellae on either side of the simple fold and sulcus. On the dorsal valve the two central ones are slightly more prominent and stronger than the others. They are wider than the interspaces. The ventral valve is only slightly convex; the dorsal valves nearly flat in some forms are gently convex in others. The beak is elevated above the hinge-line. The outline is somewhat pentagonal. The posterior margin of the ventral valve slopes at a slight angle from the beak to the cardinal angles. Any angular measurements of the inclination of this margin outward from the beaks are unreliable because of the severe pressure to which all of the specimens have been subjected. Oblique lamellae and the position of the bases of the crural processes may be seen in figures 11 and 13. Measurements of a few valves show the following dimensions: the lengths and widths are, respectively, 11 and 12 millimeters, 12 and 15 millimeters, 17 and 17 millimeters, and 11 and 18 millimeters. These specimens bear a slight resemblance to those of the *Antispirifer* described by Williams from the Moose River sandstone in Maine, but an examination of his types in the U. S. National Museum shows them to be of a different genus.

Locality: Tip Top Hill (loc. 8) and Mormon Hill (loc. 11). Museum Comp. Zoölogy, No. 8682a, b, c, and d.

Mollusca.

Pelecypoda.

Pterinea radialis Clarke.

Plate II, Figs. 5-7.

Clarke, J. M.: New York State Museum, Bull. 107, p. 207, 1907.
Williams, H. S., and Breger, C. L.: Fauna of the Chapman Sandstone, Maine; U. S. Geol. Survey, Prof. Paper 89, pp. 184, 1916.

The collection consists of a dozen specimens well enough preserved to show the outline and surface ornamentation. In only one or two of these are the wings preserved. The outline is obliquely rhomboid; height less than length and greatest just back of the middle. Hinge-line long, straight on both

sides of the beaks. The posterior end is acutely pointed; the anterior end rounded. The valves are ornamented with radial riblets, 16 to 32 in number, increasing by implantation. The radial ornamentation is not observed on the wings but the latter show, in some instances, fine concentric lines of growth. These are conspicuous on the body of the shell and in places aggregate into low, distinct varices. The oblique axis of the shell is inclined about 60° to the hinge-line. The average size of the specimens is about 17 millimeters high and 20 millimeters long.

The New Hampshire specimens are unquestionably of the same species described by Clarke and by Williams from the Chapman sandstone in Maine. Clarke, in his original description of the species, pointed out that there was some variation within the group and Williams and Breger referred the smaller specimens to the genus *Actinopterella*. The chief difference between Clarke's original *Pterinea radialis* and Williams and Breger's *Actinopterella radialis* is one of size.

Locality: Tip Top Hill (loc. 8).

Museum Comp. Zoölogy, Nos. 15056, 15057, 15058.

Gastropoda.

Gastropod gen. et sp. ind.

A single, poorly preserved specimen is a low spired shell showing only three whorls. Revolving ornamentation is present but other diagnostic features are obscure.

Locality: Tip Top Hill (loc. 8).

Museum Comp. Zoölogy, No. 27908.

Tentaculites schlotheimi Koken.

Williams, H. S., and Breger, C. L.: Fauna of the Chapman Sandstone, Maine; U. S. Geol. Survey, Prof. Paper 89, pp. 283-284, 1916.

Shell with eleven millimeters of its length showing. Eight annulations show in the space of 5 millimeters. The cone tapers from 2 millimeters in thickness to 1 millimeter near the apex. The annulations show an interspace nearly twice the width of a rib. The latter are strongly elevated and the interspaces are deeply excavated. Other finer ornamentation is obscure.

Locality: Mormon Hill (loc. 11).

Museum Comp. Zoölogy, No. 27907.

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SKULL OF *TRICERATOPS FLABELLATUS* RECENTLY MOUNTED AT YALE.

RICHARD S. LULL.

After remaining in the study series of the Yale Peabody Museum for nearly half a century, the type skull of *Triceratops flabellatus* (Cat. No. 1821 Y.P.M.) has recently been put on exhibition. This important specimen is not only the holotype of its species but, because of its disarticulated condition when discovered, it has served as a principal source of our knowledge of the ceratopsian skull. Hatcher,[1] who found the specimen in the Lance beds of Niobrara County, Wyoming, in 1889, thus described its condition at the time of discovery: "The skull lay on its left side in a bed of loose sandy marl. The right or uppermost side of the frill and the right horn core were completely weathered away, while the left squamosal and parietal, together with the left horn core and the entire cranial region and the left maxillary with palatine attached, lay in position and in an excellent state of preservation, save the horn core and a portion of the maxillary, which were extremely rotten and had to be treated with a hardening solution. The right maxillary with palatine, both premaxillaries, nasals, pterygoids, quadrates, and quadratojugals, and in fact the whole anterior portion of the skull, were detached and lay scattered about in the bed of soft sandy marl. Fortunately they were all in a nearly perfect state of preservation. The left jugal was in position, the right was detached."

The skull has remained in the condition in which Hatcher left it until recently, when it was turned over to Preparator Gibb for the final preparation and repair of the individual bones. This task was not fully finished at the time of Gibb's death in 1932. Within the present year, Fred Darby has continued the work and, together with Clifford Allderige, has completed the restoring and mounting of this remarkable specimen. Because of its disarticulated condition, it was decided to mount the skull with the various elements slightly spaced, which has somewhat increased the over-all dimensions. It was a very delicate operation necessitating great skill and ingenuity in construction of the iron supports, as nearly all of the elements are detachable for future study.

[1] Hatcher, Marsh, Lull: The Ceratopsia, U. S. Geol. Surv., Mon. XLIX, 1904, p. 144.

Some reconstruction was, of course, necessary, but the restoration drawn by Professor Marsh and published in the Ceratopsia Monograph[2] was followed as closely as possible. The left horn core, which Hatcher described as ill preserved, cannot at present be located, for it has probably disintegrated in the course of years. The nasal horn in both *T. flabellatus* and *T. serratus* arose from a separate ossification, for it was

Fig. 1. Outline drawing of *Triceratops flabellatus* after Marsh, made from the disarticulated skull, emphasizing the remarkable accuracy of the Marsh paper restorations. One-twentieth natural size.

in each instance lost in maceration and not broken off. The rostral and predentary bones were cast from other specimens and modified to fit. For the former, we are indebted to the American Museum; for the latter, the predentary of *T. prorsus* type, at Yale, was used.

The redescription of *T. flabellatus* by the author,[3] which was based largely upon the Marsh restoration, must now be qualified, in view of the completion of the type skull. The dorsal profile is not straight, as the description states, but is similar to that of most *Triceratops* species. The nasal profile which was described as "a gentle curve, the degree of which remains the

[2] Op. cit., Plates XLIV-XLV, text figures 10, 11, and 16.
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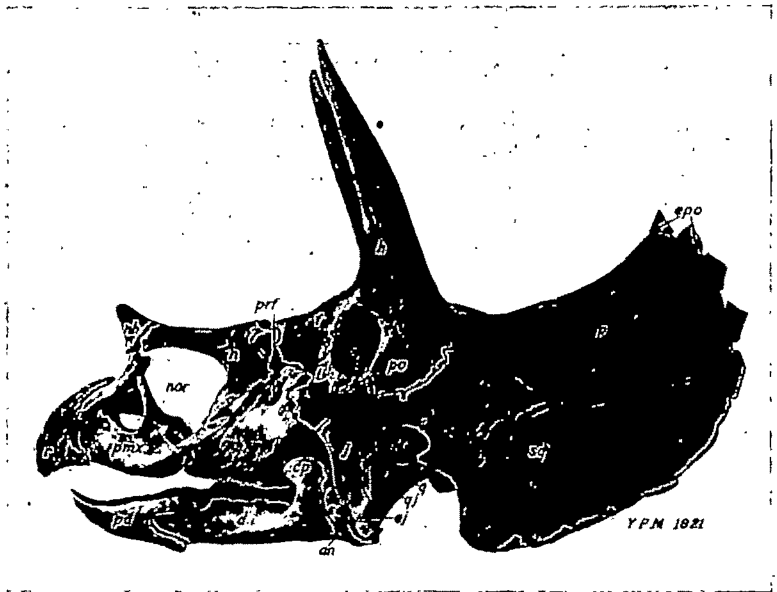

Fig. 2. Skull of *Triceratops flabellatus* Marsh, about 1/20 natural size. an, angular; cp, coronoid process; d, dentary; ej, epijugal; epo, epoccipital; f, frontal; h, brow horn; itf, infratemporal fossa; j, jugal; l, lacrymal; mx, maxillary; n, nasal; nar, narial opening; nh, nasal horn; o, orbit; p. parietal; pd, predentary; pmx, premaxillary; po, postfrontal; prf, preorbital fossa; q, quadrate; qj, quadratojugal; r, rostral; sa, surangular; sq, squamosal.

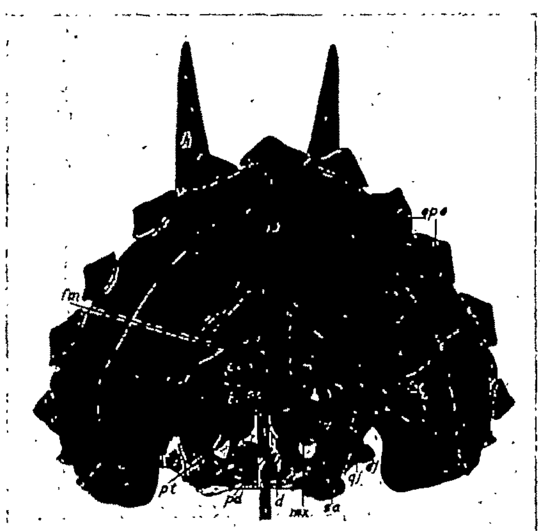

Fig. 3. The same skull, seen from behind; 1/20 natural size. bo, basioccipital; d, dentary; ej, epijugal; epo, epoccipital; exo, exoccipital; fm, foramen magnum; h, brow horn; mx, maxillary; oc, occipital condyle; p, parietal; pd, predentary; pt, pterygoid; q, quadrate; qj, quadratojugal; sa, surangular; so, supraoccipital sq, squamosal.

same throughout," was found to flatten out behind the nasal suture so as to become almost straight. The parietal profile varies from the Marsh restoration in curving upward toward the posterior end. It shows no undulations along the midline as in *T. serratus* and *T. prorsus.* The curvature of the brow horns above their base cannot be accurately determined. As restored, they are comparatively slender, straight, and erect—possibly too much so. The missing portion of the horn might have determined this curvature to be more nearly as Professor Marsh drew it. The orbit is an elongated ellipse, but the long axis, instead of being inclined at 45° from the perpendicular, is more nearly erect, the degree of inclination being about 20°. The muzzle is lengthened somewhat in the mounted specimen due to the artificial opening of the sutures, but it must have been actually somewhat longer and relatively less deep than in the former description—more as in *T. serratus.* The skull in its restored condition resembles *T. serratus* more than any other species. The variation in the apparent width of their crests may well be due to crushing, depending upon the position of the skull when found, *T. flabellatus,* the narrower, lying on its side. There is apparently no authority for the unnamed, rounded, plate-like bone which Marsh shows on either side of the face, in front of the lacrymal. In the dorsal aspect of the cranium, Marsh shows no postfrontal fontanelle, a condition found in no *Triceratops* skull other than the *T. prorsus* type. While this area of the skull under consideration has suffered from erosion, nevertheless, there is clear evidence of the existence of this aperture, although not of its exact shape. Thus, *T. flabellatus* aligns itself with the other *Triceratops* species in this regard. In *T. prorsus,* there is evidence of a secondary closure of the foramen due to extreme age. There are aged individuals of other species, however, where no evidence of closure is seen.

The ceratopsian exhibit now includes, beside the restored specimen of *Monoclonius* (*Centrosaurus*) *flexus,* the skulls of *Monoclonius, Chasmosaurus,* and the type skulls of *Triceratops prorsus, T. serratus,* and *T. flabellatus,* that of a gigantic *Triceratops* still largely inclosed in the matrix, and the type of *Torosaurus gladius.* To these will shortly be added the types of *Torosaurus latus* and *Triceratops brevicornus,* thus forming a series highly interesting in extent and perfection.

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THE LOWER ORDOVICIAN EL PASO LIMESTONE OF TEXAS AND ITS CORRELATIVES.*

EDWIN KIRK.

The present paper is in the main a discussion of the El Paso limestone and its correlatives in western Texas, New Mexico, and Arizona. As such it serves as a conspectus of a fairly large area of Lower Ordovician as developed in the western United States. Owing to the difficulty of getting good sections and adequate paleontologic collections our knowledge of the Lower Ordovician of the West is very incomplete. The area under consideration, forming as it were a connecting link between the Arbuckles and the Great Basin region, should prove serviceable in correlating between East and West. Within the area occurs one of the relatively rare cases where graptolite and normal marine faunal facies can accurately be determined as contemporaneous. Certain faunal elements can be correlated with fair assurance with regions as far removed as Newfoundland, while one faunal zone is widely developed in Texas, Nevada, and Utah and probably extends northward into British Columbia. The presentation of such facts as are known will at least serve as a point of departure for more intensive studies and establish certain key horizons and the succession of faunas as at present known. We are, moreover, dealing with portions of the Lower Ordovician in the West of approximately Beekmantown age, and with these elements more or less fixed in the time-scale it will be easier to work downward and gradually clear up the uncertainties that at present obscure satisfactory placement of the remaining post-Cambrian beds. It still remains to place certain higher horizons in the Great Basin region that seem to be pre-Chazyan but apparently are unrepresented elsewhere in North America except in Newfoundland.

The great weakness in our present studies lies mainly in the paucity of faunal evidence. Apart from facies development of the faunal elements, lithology has an important bearing on what can be collected. In the greater portion of the El Paso limestone silicified cephalopod siphuncles and sponges are about all that can be found. In the Manitou of Colorado residual cherts yield trilobites, while a fair fauna of silicified gasteropods, cephalopods, and brachiopods can be had with

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persistent collecting. In the Great Basin region good sections are rare, and while good collections are to be had the vertical range of genera and species is difficult to determine. Fortunately graptolite faunas are widely spread and in many cases are of considerable value in aligning subjacent and overlying normal marine faunas. For the time being correlations must rest largely on the recognition and use of key faunas that can be demonstrated to have a wide distribution.

I shall first give a brief historical résumé of the formation names that have been used for the Lower Ordovician in whole or part in the area under consideration. This will be followed by a more detailed description of the El Paso in the type area and a discussion of its probable distribution and interrelationships.

El Paso limestone.—The El Paso limestone as originally defined by Richardson (1904, pp. 29-30) included all the Ordovician deposits as exposed in the Franklin Mountains near El Paso, Texas. Richardson described the El Paso as having an aggregate thickness of about 1,200 feet and a faunal range, determined by Ulrich, of "Calciferous," Galena-Trenton and upper Richmond. Richardson recognized the extension of the El Paso in the Hueco Mountains and near Van Horn, Texas. Richardson (1909, pp. 3-4), on faunal grounds, restricted the El Paso to the Lower Ordovician of the type section and gave the name Montoya to the upper beds that at that time were supposed to range from Galena-Trenton to Richmond in age. As defined the El Paso was given a thickness of about 1,000 feet, mainly consisting of gray dolomitic limestone. The lower 100 feet was described as arenaceous and brownish-weathering. Locally the underlying Bliss sandstone, of Cambrian age, is absent, the El Paso lying directly on the pre-Cambrian. Above there was supposed to be no sharp line of demarcation between the El Paso and Montoya, the succession apparently being conformable and the rocks lithologically similar. Richardson gave a probable correlation of the El Paso with the Longfellow limestone of the Clifton quadrangle, Arizona, and noted the extension of the El Paso into New Mexico, as reported by Graton and Gordon. Richardson likewise quoted an opinion of Ulrich correlating the El Paso with the upper 1,000 feet of the Arbuckle limestone of the Wichita Mountains, Oklahoma. Subsequently the name El Paso was used in the Van Horn, Texas, quadrangle by Richardson (1914), in the Silver City,

New Mexico, quadrangle by Paige (1916); and in the Deming, New Mexico, quadrangle by Darton (1917). Darton correlates the El Paso with the lower part of the Mimbres limestone of Gordon.

Marathon limestone.—The term Marathon was first used by Baker in Udden, Baker, and Böse (1916, pp. 37-38) to designate a series of calcareous beds in the Marathon Basin, Texas. The formation was supposed to range in age from the Ozarkian of Ulrich to Black River or Trenton on the basis of faunal determinations by Ulrich. The use of the name Marathon was restricted by King (1931) and Marathon limestone as a formation unit dates from this paper. The Marathon limestone as defined has an aggregate thickness of from 500 to 1,000 feet, one accurately measured section giving a thickness of 800 feet. In the main the formation consists of dense, flaggy gray to black limestones with interstratified shales. Near the middle of the Marathon a 75-foot massive dolomite has been designated as the Monument Spring dolomite member. Below, the Marathon rests on the Upper Cambrian Dagger Flat sandstone. Above, it is overlain by the Alsate shale, of Beekmantown age.

Alsate shale.—The Alsate shale as defined by King (1931, p. 1069) consists of 25 to 50 feet of greenish shale with nodular beds of limestone at the type locality. Elsewhere in the general region the Alsate reaches a thickness of 125 feet and consists of alternating beds of shale and limestone. Below, the Alsate rests on the Marathon limestone, and above, it is overlain by the Fort Pena formation, of possible Chazyan age.

Mimbres limestone.—The name Mimbres limestone was given by Gordon and Graton (1906, 1907) to the series of Paleozoic limestone lying between the Upper Cambrian quartzite and the Upper Devonian Percha shale. The type area is the Mimbres Mountains in the western part of Sierra County, New Mexico. The authors recognized the composite nature of the formation as named, knowing that Lower Ordovician, Upper Ordovician, and Silurian were present in the series. It may be explained that the formation was described in the 1906 paper but not given a name until the "author's abstract" of 1907. A total of some 1,200 feet of limestones were included in the formation, of which Graton and Gordon considered about 770 feet were of Ordovician age, no line, however, having been drawn between it and the Silurian. Of this

770 feet in turn, at least 100 feet were known to be of Lower Ordovician age on fossil determinations by Ulrich. It is reasonably certain that the basal 450 feet as described by Gordon and Graton are equivalent to the El Paso, the cherts being highly characteristic. The name Mimbres, representing the undifferentiated post-Cambrian-pre-Devonian Paleozoic, has been used very little and has been discarded.

Longfellow limestone.—The Longfellow formation was described by Lindgren (1905, pp. 62-66) with its type area in the Clifton-Morenci mining district, Arizona. As described, it has a thickness of about 400 feet overlying the probably Upper Cambrian Coronado quartzite. It is overlain by the Morenci shale, of Upper Devonian age. In lithology the Longfellow is described as "consisting of limestones usually more or less dolomitic and gradually growing more siliceous near their lower limit. The upper 150 feet always form a prominent bluff of brownish limestone, while the lower 250 feet contain more shaly strata." A few fossils were found 20 feet above the base of the Longfellow that Walcott identified as probably Upper Cambrian. In the upper beds of the Longfellow, the fossils as determined by Ulrich, are of Lower Ordovician age. Darton (1925, pp. 53-54) found a Lower Ordovician fauna near Dos Cabezos, Arizona, as determined by Kirk. Darton was "deeply impressed with the strong resemblance of the Longfellow and El Paso limestones."

Abrigo limestone.—The Abrigo limestone was named by Ransome (1904, p. 30) and derives its name from Abrigo Canyon near Bisbee, Arizona. As defined by Ransome the Abrigo has a thickness of 770 feet, resting on the Bolsa quartzite (Cambrian) below and overlain by the Martin limestone (Devonian). The Abrigo is described as a thin-bedded limestone with intercalated thin sheets of chert and gray limestone. At times the beds carry considerable amounts of quartz sand and show cross-bedding. In the lower half of the Abrigo fissile greenish calcareous shales are a characteristic feature. The age of the Abrigo was made Middle Cambrian to accord with fossil identifications made by Walcott. At present this fauna would be considered Upper Cambrian rather than Middle. Ransome (1920, p. 101) notes the presence of the Abrigo in the Tombstone district, Arizona, but gives no information regarding it other than that it is 70 feet thinner than at Bisbee. Darton (1925, p. 46 et seq.) gives a summary of

our present knowledge of the Abrigo. He has found the Abrigo on the north end of the Tucson Mountains, in the Santa Catalina Mountains, in the Vekol Mountains, and in the canyon of the Gila River just below Needle's Eye. From all these localities Darton collected Upper Cambrian fossils.

Texas.

We are fortunate in having an almost linear sequence of described sections of the El Paso and its equivalents extending in a northwest-southeast direction from the Marathon Basin, Texas, to Silver City, New Mexico, a distance of over 350 miles. From east to west the areas are as follows: Marathon Basin, Van Horn, and El Paso in Texas; Deming and Silver City in New Mexico. The El Paso section will be discussed first as being the type section of the formation.

Very brief visits to the type section some years ago and in 1930 have yielded a considerable amount of additional evidence as to the faunal content of the El Paso, particularly as regards the upper portion of the formation. Under the guidance of P. B. King, I have examined the section in the Marathon Basin. I am not acquainted at first hand with the other sections except as having handled and reported on the paleontologic collections. Following the discussion of the El Paso section, the Van Horn and Marathon Basin areas will be taken up, and then the sections to the northwest of El Paso will be described. After this the probable extension of the El Paso equivalents to the westward into Arizona follows in logical sequence.

El Paso.—The new scenic highway that has been constructed around the southern end of the Franklin Range gives an excellent section of the greater portion of the El Paso. At the crest of the drive a broad platform has been cut in the cliff that shows a considerable amount of the uppermost El Paso that has hitherto not been available. On the dip slope on the west side of the range a careful search around the bases of the Montoya remnants yields faunas not to be found elsewhere. The lower portion of the El Paso is best shown in an accessible section along the power line on the east side of the range. The section as given was measured for above one-half its thickness and I think fairly accurately estimated and measured for the remaining portion. The section was measured along the road, and in the lower portion an offset was necessary to

the quarries northward. The description of the basal portion is from a section farther north along the power line. The section as given with the basal portion not shown gives a thickness of 960 feet, which with the missing portion would about give 1,000 feet, Richardson's original estimate. In studying the sections on the Franklin Range the faults should be located. There are two longitudinal faults, one at the foot of the western dip slope of the main ridge and a much smaller one near the crest of the range. Along the crest of the range there are several cross faults with throws of apparently from 50 to 75 feet, the beds dropping in each instance to the south. The result of this progressive stepping down of the strata is that although the sharp crest of the range rises steadily in altitude as one goes northward, the El Paso-Montoya contact remains practically at the divide. These cross faults are apt to cause confusion in tracing beds, the upper beds of the El Paso apparently belonging in the Montoya, as projected according to dip and strike.

Montoya (Upper Ordovician)
  Erosional disconformity.
El Paso
  12′. Limestone with shaly partings, weathering buff to brownish.
    Fauna:
      Cybelopsis sp.
      Pliomerops sp.
      Petigurus sp.
      "Asaphus" cf. curiosus Billings
      Syntrophia cf. obscura Hall and Whitfield
      Taffia near iones (Walcott)
      Archaeorthis sp.
      Deltatreta sp.
  6′. Massive fine-grained dolomite.
  6′. Limestone much like 12′ bed at top.
  6′. Shale with lenticular limestone.
    Fauna:
      Isoteloides sp.
  10′. More massive limestone.
    Fauna:
      Archaeorthis sp.
  5′. Shaly beds.
    Fauna:
      Numerous fragmentary gasteropods, trilobites, and cystids.

The beds, as given above, seem to form a faunal unit, the contained fauna as explained elsewhere being a widespread one. There is a sharp lithologic break between these beds and the underlying ones.

45′. Massive bluish dolomitic limestone, with fine anastomosing chert in lower two-thirds. Platy weathering. This forms the first cliff below the Montoya.

15′ Gap, probably representing shaly beds. A trail to the crest of the range follows this zone.

65′. Massive dolomite, cross-bedded in some layers. Thin lenses of sandstone. On the crest of the range this is probably the horizon that yields a silicified gasteropod fauna.

Fauna:

Ceratopea sp.
Coelocaulus? sp.
Helicotoma sp.
Hormotoma sp.
Euconia sp.
Roubidouxia? sp.

There is some question as to whether this series of beds does not constitute a stratigraphic unit, possibly including the 210-foot limestone immediately subjacent. The gasteropods of these beds have not been found below, and the highly characteristic cephalopods and sponges of the lower sequence have not been found here.

210′. Massive bluish limestone with shaly partings. The latter tend to weather reddish. Wave ripples 4 inches in depth and from 2 to 3 feet from crest to crest can be found on some of the surfaces. Some beds of crystalline limestone. Chert.

Fauna:

Small poorly preserved gasteropods are abundant in some of the shaly layers. Lithologically the beds suggest those on the main slopes of the range that carry the sponges and cephalopods of the lower division.

240′. Bluish limestone and dolomitic limestone. Some chert. Reddish shale partings.

Fauna:

This is undoubtedly in part the horizon that carries the characteristic fauna of the lower portion of the El Paso.

Calathium cf. anstedi Billings.
Piloceras sp.
Cameroceras sp.
Colpoceras sp.
Ceratopea sp.
Ozarkispira sp.
Ophileta sp.

120′±. Massive dolomite. This is the rock that is mostly quarried and crushed in the quarry north of the road.

100′±. Thinner bedded dolomite. The base of this must fall near the base of the El Paso.

To the north of this section along the power line the Cambrian and overlying beds are well shown. The Cambrian Bliss sandstone is a dark reddish-brown, cross-bedded, glauconitic sandstone. Immediately overlying it is light-colored, almost white quartzite some 25 feet in thickness that breaks down in blocks and plates. The stratigraphic assignment of this quartzite is doubtful. There is a sharp break with the underlying Bliss, and there seems to be a sharp line of demarcation between it and the overlying El Paso. The basal 15 feet of what may be taken as undoubted El Paso is a cross-bedded dolomitic sandstone. The assignment of the basal 150 feet or so of the El Paso as here defined is based on apparent lithologic continuity with the overlying beds and some paleontologic evidence. A large *Ophileta* was seen within 150 feet of the base of the El Paso.

As indicated above by notes interpolated in the section, the El Paso is divisible into at least two or possibly three units, fairly well defined both by lithologic and faunal characteristics. In an area of detailed mapping two and perhaps all three of these units would be accorded formation rank. This seems neither useful or desirable at present. For our present purposes the two major units will be designated by biologic names chosen from the contained fauna. These must be considered arbitrary as the vertical range of the genera is by no means established. The lowest horizon will be called the *Piloceras-Calathium*. The middle zone as known is characterized by a fauna mainly consisting of gasteropods, none of which is particularly diagnostic except *Ceratopea*, which, however, ranges down into the *Piloceras-Calathium* horizon. It may well prove that the *Ceratopea-Calathium* and the gasteropod horizons are only facies developments of the same widespread

fauna, and I shall not differentiate them here. The uppermost horizon will be known as that of *Taffia*. This fauna is a distinctive one and can be recognized over a great area, either by the brachiopod from which it takes its name or by the characteristic brachiopod and trilobite associates.

Richardson's statement that the separation of the El Paso and Montoya could only be made on a faunal basis and that there is no break in the lithologic succession is misleading. The abrupt cliff of the basal Montoya of the very dark dolomitic limestone is in striking contrast to the calcareous shales and limestone of the immediately subjacent El Paso. It is also quite unlike the more massive type of El Paso still further down in the section. There was a considerable but unknown amount of erosion in pre-Montoya time. Within half a mile north and south along the range there appears to be differential erosion to an amount of not less than 10 feet. Wherever the El Paso-Montoya contact is exposed for a distance of a few feet the contact is seen to be irregular. At the base of the Montoya is a thin dolomitic sandstone.

Van Horn quadrangle.—The Van Horn area is of interest as lying about midway between El Paso and the Marathon Basin. According to Richardson (1914) the El Paso in the Van Horn region has a maximum thickness of about 1,000 feet. In places the El Paso has been completely removed by pre-Pennsylvanian erosion. In the basal portion of the El Paso there are irregular lenses of white sandstone 5 to 50 feet in thickness. The fauna of the El Paso in the Van Horn area is identical with that of the El Paso at El Paso, with the exception that the *Taffia* zone has not been found. Unfortunately the collections of fossils made here were not placed in a measured sequence, and it is not possible to determine associations and range of the genera.

Marathon Basin.—In this area, largely because of lithologic differences, the name El Paso has been superseded by the names Marathon limestone and Alsate shale. The lithologic characters of the two formations are given above as of the type locality. Such evidence as we have suggests that the Marathon limestone correlates with the *Piloceras-Calathium* zone and the Alsate with the *Taffia* zone. In the Monument Spring member of the Marathon limestone the characteristic sponge-cephalopod fauna of the lower El Paso is well developed. *Calathium*, *Piloceras* and *Colpoceras* are represented by identical species with those in the lower El Paso. The

graptolite faunas, which are the most outstanding paleontological contribution of the Marathon, are being studied by Ruedemann. Pending more detailed study, it is, I think, safe to correlate the graptolite faunas of the Marathon with the second or *Tetragraptus* division of the Deep Kill section. *Tetragraptus*, *Phyllograptus*, *Didymograptus*, *Goniograptus*, *Loganograptus*, and *Dictyonema* have been found. Specific determinations of some of these graptolites, made by Ulrich, are given by Baker and Bowman (1917, p. 84). They are as follows:

Didymograptus cf. extensus
Tetragraptus aff. fructicosus
Phyllograptus cf. ilicifolius and angustifolius

The Alsate shale, according to preliminary reports by Ruedemann, contains the following graptolite genera as listed by King (1931, p. 1070): several species of *Didymograptus*, *Tetragraptus*, *Phyllograptus*, *Didymograptus*, and the unusual genus *Oncograptus*. A collection of *Maclurites* made by King and myself was considered to have come either from the uppermost Alsate or the basal Fort Pena. King lists it as Alsate. This *Maclurites* is very like a species that is characteristic of the *Taffia* zone of the Eureka district, Nevada. The Alsate may well represent the *Taffia* zone, although it may fall somewhat lower.

New Mexico.

The El Paso of New Mexico has been described by Darton (1917) in the Deming Folio and by Paige (1916) in the Silver City Folio. The sections are essentially the same. As given by Darton the El Paso varies from 500 to 800 feet in thickness. Paige states that the El Paso probably does not exceed 900 feet in thickness, but his thickest measured section shows only 655 feet. As described by Darton in his area the El Paso consists in the main of slabby limestone and dolomitic limestone, with portions somewhat cherty. Some of the beds contain considerable amounts of sand and clay. *Calathium*, *Piloceras*, *Ozarkispira*, and the other typical fossils of the lower El Paso have been found in this region. No fossils indicating the *Taffia* zone have been collected, and it is probable that this horizon has been removed by erosion.

ARIZONA.

It is evident from the faunal lists supplied by Ulrich and Kirk to Lindgren (1905) and Darton (1925) that the upper part of the Longfellow limestone correlates with the lower El Paso. The Ordovician portion of the formation as described is probably the cliff-forming upper 150 feet of brownish limestone. The more shaly basal 250 feet are probably Upper Cambrian in part. From the Abrigo limestone nothing but Cambrian fossils has been collected, but it is quite possible that the upper part of this formation is of El Paso age. Under the circumstances, when future more detailed work permits the discrimination of the Cambrian and Ordovician it would seem best to restrict by redefinition the Longfellow to beds of Ordovician age and the Abrigo to beds of Upper Cambrian age. Darton (1925, p. 50) suggests on lithologic similarity that the Muav limestone of the Grand Canyon region is the equivalent of the Longfellow, Abrigo, and El Paso. He further states that it is his belief that the basal El Paso will yield Cambrian fossils. Darton's statements in regard to the possible extension of the stratigraphic range of the fossils need not concern us. We are dealing with Upper Cambrian and Beekmantown, so there is little danger of mistaking the faunas. I very much doubt if there is a chance of Cambrian occurring in the El Paso. If, however, Cambrian should be found in the basal 150 feet of the El Paso as here described such a moiety would be excluded from the El Paso and fall with the underlying Cambrian. There is always a possibility that when not removed by erosion an El Paso equivalent will be found widely through southern Arizona, but, as suggested above, a redefinition of the Longfellow and Abrigo would take care of the situation.

The El Paso limestone and its equivalents as described above in Texas, New Mexico, and Arizona, may be considered essentially continuous in present geographic terms, as future work will doubtless interpolate sections in some of the gaps that now exist. Ranging westward, northward, and eastward there are larger discontinuities that will not be filled in the future but may be bridged by faunal evidence. It is evident that the El Paso sea was but a part of a much more extensive seaway that covered parts of Oklahoma, Colorado, and Nevada and extended widely beyond these areas. It remains, therefore, briefly to indicate the more salient points of resemblance

between the El Paso and the formations in more distant areas that are probably of equivalent age as evidenced by their faunal content.

NEVADA.

In Nevada the areas chosen for comment are Pioche, White Pine, and Eureka. The sections in the Las Vegas quadrangle are of great interest, but as yet the section has not been described nor the formations named. The stratigraphy of the Pioche district has been described by Westgate (1932). The White Pine district is the type area of the Pogonip limestone, while a considerable amount of information is available in regard to the Pogonip of the Eureka region.

Pioche district.—In the Pioche district in southern Nevada, Westgate (1932, p. 14) names and describes the Lower Ordovician Yellow Hill limestone. Unfortunately the contact of the Lower Ordovician with the Upper Cambrian could not be found in the region, and an unknown amount of the basal Lower Ordovician was not seen. It is probable that at the north end of Ely Springs Range very little of the uppermost Yellow Hill is wanting. The throw of the fault separating the Yellow Hill formation and the adjacent Chazyan Tank Hill limestone increases in magnitude from north to south, and near the north end of the range it appears to be of minor dimensions. The Yellow Hill formation as seen measures approximately 670 feet. Thin-bedded limestones with intra-formational conglomerates and thin beds of shale characterize the formation. The fauna from the upper portion of the formation as determined by Kirk some years ago is as follows:

Calathium sp.	Liospira sp.
Syntrophia calcifera	Hormotoma sp.
Taffia sp.	Eccyliopterus sp.
Orthis sp.	Asaphus? curiosus
Tetranota sp.	Pliomerops sp.

The *Syntrophia, Taffia, Orthis* (=*Deltatreta*), "*Asaphus*" *curiosus*, and *Pliomerops* are very near or identical with the forms found in the uppermost beds of the El Paso at El Paso. *Megalaspis* also occurs in this fauna. Stratigraphically above the Yellow Hill formation is the Tank Hill limestone. It may be noted in passing that the basal beds of the Tank Hill as described carry the widespread "*Receptaculites*" fauna that

until recently has been referred to the Chazyan. It is probable that the assignment is in error and the beds in question fall within the *Didymograptus bifidus* zone and would be classed as pre-Chazyan.

White Pine district.—In the Pogonip limestone on Pogonip Ridge about 1,200 feet below the Eureka quartzite I have collected a fauna that represents approximately the *Taffia* horizon as known at El Paso, Texas. An identical *Syntrophia* and a very like or identical *Petigurus* together with *Taffia* and a large *Isoteloides* seem to fix this fauna fairly accurately. Below this horizon on Pogonip Ridge exposures are poor and fossils very scarce.

Eureka district.—The *Taffia* zone is well developed in this area in the Pogonip limestone. Walcott (1884, p. 98) notes the presence of "*Asaphus*" *curiosus* at Eureka, but unfortunately no horizon or locality is given, and the specimens with their original locality number have been mislaid. In the Antelope Range about 30 miles southwest of Eureka the *Taffia* zone is well shown. "*Asaphus*" *curiosus* is present in considerable numbers, and associated with it are abundant *Archaeorthis* and *Taffia*. *Phyllograptus* cf. *loringi* White was also found, together with considerable numbers of *Maclurites* ranging in diameter from an inch to an inch and a half. The zone may be collected at the foot of the range where it has been dropped by faulting or up on the west face of the range where its relations to the overlying beds are well shown. Immediately above the limestones, sandstones, and shales of the *Taffia* zone is a thin sequence of shales and slabby argillaceous limestones. These form saddles and receding slopes as a rule, and no good exposure was seen. Above these argillaceous beds the massive cliff-forming limestones characterized by *Mitrospira longwelli* Kirk occur. It is probable that this horizon also carries "*Receptaculites*," for the two forms have been found associated in the Las Vegas quadrangle, Nevada. As seen, the *Taffia* zone ranged through at least 850 feet of limestones. Below this the sequence is not well shown and is disturbed by faulting.

Whether the *Piloceras-Calathium* zone is represented in the general area is unknown. I have never seen a good section of the lower Pogonip. Little faith can be placed in the sections and faunal lists hitherto published, as the collections have been made at widely separated points in a region greatly disturbed by faulting.

COLORADO.

In the Rocky Mountains of Colorado is a fairly extensive development of the Manitou limestone. The relation of the Manitou and underlying Upper Cambrian have not as yet been satisfactorily worked out. Most of the collections available are either float or are not accurately placed in the section. The typical Manitou is of Beekmantown age and correlates with the lower El Paso. *Calathium* has not been found, but *Colpoceras*, *Piloceras*, *Ozarkispira* and a considerable assemblage of undescribed forms are represented in both formations by identical or nearly allied species. I have not seen any signs of the *Taffia* horizon, and if ever present it has been removed by post-Beekmantown erosion, which cuts more and more deeply into the Manitou as one goes westward in Colorado. If this horizon is ever found it will be as a remnant somewhere along the Rocky Mountain Front.

UTAH.

The Garden City limestone described by Richardson (1913) consists of about 1,000 feet of limestones. The upper 300 or 400 feet at least of this formation correlates with the *Taffia* zone. *Taffia* itself is present together with a typical assemblage of other fossils, including "*Asaphus*" *curiosus*. About 150 feet from the top of the formation I have collected *Calathium*, which is of considerable interest, for although differing specifically from the the El Paso forms it extends the range of the genus upward. The typical *Piloceras-Calathium* fauna may be represented in the lower part of the Garden City, although not as yet seen. The underlying St. Charles, classed as Upper Cambrian, is probably Lower Ordovician in part.

BRITISH COLUMBIA.

In British Columbia the only formations with which we are immediately concerned are the Mons, Sarbach, and Glenogle. The best general treatment of these formations is to be found in Walcott (1928), though for details one must consult his earlier papers. Each of these formations has been used in a rather indefinite way, and in no two sections can one be sure as to the upper and lower boundaries of the formation. The Sarbach carries the "*Receptaculites*" zone of the Great Basin

region which overlies the *Taffia* zone as known in that region. The brachiopod and graptolite elements of the fauna, however, indicate close relationships with the *Taffia* zone. The species of *Deltatreta, Syntrophia,* and *Taffia* are very similar or identical in the two. *Megalaspis* occurs in the Sarbach. The *Piloceras-Calathium* zone probably finds its equivalent in the lower Glenogle graptolite shales and in the upper Mons. *Piloceras* has not been found. Whatever the reason may be, cephalopods are exceedingly rare in the Lower Ordovician of British Columbia. The identification of this horizon in the future will probably depend on the brachiopod, gasteropod, and trilobite elements in the fauna, when they are better known. Walcott's *Ozarkispira* of the upper Mons, for example, is found commonly in the *Piloceras-Calathium* zone, but lacking knowledge of the vertical range of the genus this evidence is not conclusive.

Central Texas–Oklahoma.

The El Paso limestone probably correlates with the upper part of the Ellenburger limestone of the Central Mineral Region of Texas. It probably does not go below the Roubidoux equivalent of Dake and Bridge (1932) and almost certainly correlates in part with the Cotter equivalent of Dake and Bridge. The sponge figured as *Calathium* sp. on Plate 12, Figure 15, and stated to be of similar type to those found in the Monument Spring of the Marathon region is *Archaeoscyphia*, whereas the El Paso sponges appear to be typical *Calathium*. When the faunas of the Ellenburger limestone are better known, correlations on the one hand with the El Paso and on the other with Missouri and Arkansas formations should be possible.

In Oklahoma the middle to upper portion of the thick Arbuckle limestone doubtless correlates with the El Paso. The *Ceratopea* fauna ranges well down in the Arbuckle limestone, and this zone may be taken as the approximate equivalent of the El Paso.

Missouri–Arkansas.

In the Ozark region of Missouri and Arkansas there are undoubtedly equivalents of the El Paso in whole or part. It is probable that the El Paso does not range lower than the Jefferson City, but a correlation between the Jefferson City

and lower El Paso would not be justified with our present knowledge. The Cotter and Powell can be correlated with the El Paso with fair assurance, while the Black Rock and Smithville, with their graptolite and brachiopod faunas, may be correlated with the *Taffia* zone with fair assurance.

Alabama.

The Newala and Odenville of Alabama may be correlated with the El Paso with fair assurance. Whether the El Paso correlates with still older formations in this region is uncertain.

Newfoundland.

Inasmuch as a monographic report on the Paleozoic section of Newfoundland is soon to be made by Schuchert and Dunbar, very little will be said in regard to this section other than to correlate with the El Paso. Horizons G and H of Logan and Billings and perhaps F may safely be correlated with the *Piloceras-Calathium* horizon of the El Paso on the basis of the contained faunas. The stratigraphic succession and faunas of the Lower Ordovician rocks (of Beekmantown and Chazy ? age) in the Western United States and Newfoundland are strikingly similar. Horizon N of Newfoundland is well developed in Nevada, lying above the *Taffia* zone. It will probably prove that the intervening formations between the *Piloceras-Calathium* horizon and N will show equally strong resemblances in the two areas, and that the characteristic fauna of the *Taffia* zone is present.

North Greenland.

Poulsen (1927) has described a fauna in the Nunatami formation of North Greenland that is very like that characterizing the *Taffia* zone. He lists *Cybelopsis*, *Pliomerops*, *Isoteloides*, *Phyllograptus angustifolius*, and *Didymograptus bifidus*. Poulsen correlates the Nunatami with the Upper Canadian. There can be little question that the Nunatami fauna has approximately the stratigraphic position of the *Taffia* zone. The *Pliomerops* and *Cybelopsis* as figured by Poulsen can scarcely be distinguished from forms in this zone in Nevada.

GREAT BRITAIN.

The upper portion of the Durness series in the north of Scotland has long been correlated with the Beekmantown "Calciferous" of eastern North America. Excellent summaries of the Durness problem from American and British points of view are to be found in Grabau (1916) and Peach and Horne (1930). How far down in the Durness series the Beekmantown extends is not certain, but it would appear that it carries well down into the Sailmhor group at least. The fauna of the Balnakiel and Croispol (Croisphuill) groups is almost certainly to be correlated with G and H of the Newfoundland section and the *Piloceras-Calathium* horizon of the El Paso. The conclusions reached by Peach (Peach and Horne, 1930, p. 98) in placing this fauna in the Cambrian should prove of interest to American geologists. Peach, though following precedent, was apparently influenced by the finding of Arenig graptolites above this horizon in Newfoundland. It is obvious that British and American conceptions of the Ordovician are widely at variance, and we are given an excellent argument in favor of the use of Canadian as a system, somewhat as proposed by Dana. The Canadian portion of the Durness will prove to be the equivalent of the *Tetragraptus* zone of the Arenig and not of the Tremadoc of Wales, as thought by Peach.

CHINA.

In China the *Piloceras* horizon is represented in the Peilintze and Lianchiashan limestones of North China as described by Grabau (1922). The general character of the associated fauna, meager as it is, bears out the correlation.

THE FAUNAL ZONES.

It appears from the foregoing discussion that there are two widespread and distinctive faunal aggregates in the El Paso limestone, the *Piloceras-Calathium* and the *Taffia* zones. Future studies will doubtless throw much light on the vertical range of the component genera of these faunas, but as at present known the two faunas do not seem to overlap and in distribution appear to have separate histories. We are, of course, constantly beset by the difficulties of evaluating facies developments of faunas. This is a very real problem despite attempts

to simplify correlation by arguing or denying its validity. The apparently relatively shallow-water and near-shore graptolite facies can in time by such fortunate finds as those in the Marathon Basin accurately be tied in with normal invertebrate faunas. The unequal distribution of genera, and even of classes and phyla, is a much more difficult problem and can, I think, be solved only by tracing the faunas laterally and noting accretions and deletions as they occur. I am giving a brief résumé of such faunal elements in the two zones as seem to range widely.

The peculiar type of *Piloceras* found in the lower El Paso will, I think, be found very useful in long-range correlations. As noted elsewhere, it is found in China, Newfoundland, and Scotland. The problematic *Ceratopea* is likewise widely distributed and probably is of considerable stratigraphic value. It is found in the upper part of the Arbuckle limestone of Oklahoma, the Cotter of Missouri and Arkansas, the Newala of Alabama, and up along the Appalachians into Pennsylvania, where it is found in the high Beekmantown Bellefonte dolomite. *Calathium* may likewise be found useful when more carefully studied. It has been found in Newfoundland and Scotland. No doubt in time more fossils will be found in this zone that have diagnostic value as well as wide distribution. Curiously, *Piloceras* has not as yet been found in the Great Basin region of Nevada and Utah or in British Columbia. In this general area Beekmantown cephalopods are rarely found. The genus so far as I know has not been found in the Appalachian region south of New York. The apparent absence of *Piloceras* in these areas does not mean that contemporaneous deposits are wanting. The somewhat meager evidence of other fossils indicates the contrary. Correlating the *Piloceras-Calathium* zone with the second or *Tetragraptus* horizon, of the Deep Kill section, makes possible widespread inter-continental correlations of the graptolite facies of this time interval.

The genus *Taffia* seems consistently to hold a fairly closely circumscribed stratigraphic range in the West. It is found in the upper Mons (according to Walcott) and the Sarbach of British Columbia, the upper Garden City of Utah, the upper part of the lower Pogonip and the upper part of the Yellow Hill formation of Nevada, and the uppermost El Paso of Texas. It likewise occurs in the Odenville of Alabama and according to Cooper, to whom I am indebted for careful deter-

minations of the brachiopods listed in this paper, in the Black Rock of Arkansas, and at Fort Cassin, Vermont. Associated with *Taffia* are usually found one or more of the following genera: *Archaeorthis*, *Deltatreta*, and a distinctive *Syntrophia*. According to my personal experience this brachiopod assemblage is of great stratigraphic value. "*Asaphus*" *curiosus* has been found in the upper El Paso, the upper Yellow Hill, and upper part of the lower Pogonip in Nevada, the upper Garden City of Utah, and the Ordovician of "Stanbridge, range 6, lot 20," Quebec. The other trilobites are of uncertain value as yet owing to our lack of knowledge of their stratigraphic range and exact generic affinities. The *Cybelopsis* found in the upper El Paso of Texas, upper Yellow Hill of Nevada, and the Nunatami formation of North Greenland seems, however, to be useful. In the Sarbach of British Columbia *Phyllograptus* cf. *ilicifolius* and a *Didymograptus* near *bifidus*, have been found. I have found *Phyllograptus* of the type of *ilicifolius*, which probably is White's *P. loringi*, associated with "*Asaphus*" *curiosus* and its associated fauna in the upper part of the lower Pogonip near Eureka, Nevada. Poulsen (1927) identifies *Phyllograptus angustifolius* and *Didymograptus bifidus* in the Nunatami formation of North Greenland. *Phyllograptus* and *Didymograptus* of the *bifidus* type are found in the Smithville of Arkansas, which immediately underlies the Black Rock, which in turn carries the characteristic brachiopod fauna of the "*Asaphus*" *curiosus* zone.

The occurrence of *Oncograptus* and *Cardiograptus* in the Lower Ordovician of Western North America is of very great interest. Ruedemann (1927) has pointed out the importance of these genera in establishing correlations between Australia and North America. *Oncograptus* is found in the Alsate shale of the Marathon Basin, Texas, *Cardiograptus* in unnamed Lower Ordovician graptolite shales in the Wood River region of Idaho, and both *Oncograptus* and *Cardiograptus* in the Glenogle formation of the Stanford Range, British Columbia. In British Columbia and Idaho the genera occur associated with *Didymograptus bifidus* or a variant that bears the *nomen nudum* of *D. walcottorum*. Ruedemann correlates this horizon with the second division of the Deep Kill section but states that the forms range upward with associates that indicate the third Deep Kill horizon. In my experience I have not found that the graptolites have the narrowly limited ranges postulated from their zoned occurrence in the few feet

of section at Deep Kill, New York. A graptolite fauna commonly ranges through 1,000 feet or more of shales in western North America. The range of *Didymograptus bifidus* and its near congeners, for example, instead of being a narrow zone is a fairly broad band in the Ordovician stratigraphic succession of the West. The graptolite faunas are of the greatest value in correlation, but it should be borne in mind that a vertical range of a few inches or a few feet in one region does not necessarily indicate an equally narrow range elsewhere. As a corollary it is not to be expected that closely circumscribed associations of genera and species will be found in widely separated regions. I think that the *Oncograptus-Cardiograptus* horizon may fairly safely be correlated with the *Taffia* zone, although we do not as yet have proof that this is the case.

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MADAM PIERRE CURIE

(MARIE SKLODOWSKA CURIE)

Madam Pierre Curie, whose death took place on July 4, 1934, in a sanatorium near Sallanches (Savoy), has long been regarded as the foremost woman scientist. She was actively engaged to the end of her life as professor of physics in the Sorbonne, director of the Radium Institute in Paris, and particularly as an investigator of the physical and chemical properties of radioactive substances. Her death was due to an anaemic condition brought about by much exposure to radioactive radiations.

She was born November 7, 1867, of Polish parents and was the youngest of five children. Her father was a professor of physics and mathematics at a lycée in Warsaw (Russian Poland), and her mother was director of a girls' school in the same city. Her early education was obtained from her parents, in private (Polish) schools and a lycée in Warsaw. After graduation from the lycée she engaged in private teaching as a governess for nearly five years. During this period she had definitely made up her mind to go into scientific work with physics as her choice and carried on solitary study to be prepared to enter the Sorbonne. The czarist persecution of the Polish nationality influenced her—as it did many other students—to be active for her native Poland by giving much time and energy in assisting in popular education of her countrymen. Her great love for her native land was shown by many acts all through her life.

Towards the end of the year 1891 she departed for Paris and entered as a student in the Sorbonne. Finding her mathematical preparation insufficient she was obliged to spend vacations in further mathematical studies but in 1895 she graduated at the head of her class in physics and second in mathematics.

In the spring of 1894 she met Pierre Curie (1859-1906); he was a young professor in the School of Physics and Chemistry of the City of Paris, whose work in magnetism, crystallography, and on the piezoelectric effect (with his brother Jacque Curie) is well known to students of to-day. In 1895 she became his wife. At this period her scientific work was an investigation of the magnetic properties of steel, while Pierre Curie's work was in the realm of crystallography.

The discovery of radioactivity of uranium in 1896 by Henri Becquerel became the turning point in the scientific careers of both Pierre and Marie Curie, since they decided to give their attention to this new discovery. In order to carry the work on the radioactivity of uranium beyond the results of Becquerel, they substituted the electrical method (based on ionization effects) for the photographic method in their investigations. For this purpose the quartz piezoelectric electrometer of Pierre and Jacque Curie was

immediately put to use and later other forms of suitable electrometers were devised. Mme. Curie first showed that the radioactivity of uranium was an atomic phenomenon and that it was in no way conditioned by chemical combinations of uranium, or on external circumstances such as light and temperature. She soon discovered that thorium was also radioactive. Upon investigating uranium minerals she discovered that the activity of the mineral, for a given uranium content, was about four times as great as that of the uranium itself. She was thus led to the conclusion that some more active element than uranium (or thorium) must be present in the mineral. She wrote in her biographical notes: "I had a passionate desire to verify this hypothesis as rapidly as possible." The two started their work on the pitchblende from Jachymov (Joachimstahl), Bohemia. Their laboratory was a shed on the grounds of the school. It was disused for other purposes, inadequate, and with no equipment to speak of. Yet it was here that they did all their important scientific work up to 1906.

In July, 1898, they announced the discovery of polonium and in December the discovery of radium. Being acquainted with the methods used by the Austrian Government at the Jachymov mines to separate uranium from the pitchblende, they realized that at these mines the radium residues were thrown away. The Austrian Government gave them a ton of these residues and later, at the solicitation of the Vienna Academy of Sciences, sold them more of this material at a moderate cost. At great physical labor they worked up this material, obtaining from it a sufficient quantity of pure radium chloride for the determination of the atomic weight of radium (1907). During 1899-1900 they discovered what was for many years called "induced radioactivity," but which was shown by Rutherford in 1905 to be active deposit of the disintegration products from the "emanations" (radon, thoron or actinon). They investigated the chemical and luminous effects of the rays, the electrical nature of the alpha and beta rays and the heat produced by the radiations from radium.

In 1903 the Royal Society of London bestowed on them the Davy medal and in the same year they were awarded, with Henri Becquerel, the Nobel Prize in Physics. Pierre Curie was made a professor of physics in the Sorbonne in 1904, but in 1906 he died, being killed by an automobile truck on a street in Paris. Mme. Curie was appointed his successor as professor in physics in the Sorbonne. During the following years she had much work taxing her energies: duties as professor, attending to the education of her two daughters, and attempting continuous research, with the result that her health gave way in 1911. In 1911 she was

awarded the Nobel Prize in Chemistry for isolating radium as an element (metal). She is the only Nobel Laureate who has received two Nobel Prizes.

One cannot pass over the war period and her activity in it without realizing the unselfish work she did for France and humanity. She equipped several hundred radiological cars as complete X-Ray units for the armies of France, trained the men to use them and when these men were frequently ordered for other military service, she instituted a radiological department with the Nurses' School of the Edith Cavell Hospital to replace men operators by women. She herself, on many occasions, drove a radiological car and she was on all the battle fronts looking after the radiological work. In 1915 her radium, which she was ordered to remove to Bordeaux after the first German drive on Paris, was returned to Paris and ultimately (1915) placed in its present home, the Radium Institute in Rue Pierre Curie. With no time for scientific research she put the radium to use for radium therapeutic work for the wounded, preparing, herself, all the radon bulbs for this purpose. There is no doubt that she was much exposed to radiations during this period.

In 1921 she visited the United States. The women of America contributed to a fund to buy her a gram of radium for her researches and this was presented to her by President Harding in a ceremony at the White House on May 20, 1921. She visited many American Universities and Colleges, receiving honorary degrees from many of them, including Yale. She was also awarded the John Scott medal, the Benjamin Franklin medal and the Josiah Willard Gibbs medal.

Much work was initiated by her at the Radium Institute. In this she and her daughter and son-in-law, Irene Curie and Frederick Joliot, and S. Rosenblum have contributed to the most recent and important work in physics, notably on the neutron, the fine structure of alpha radiations and the discovery (by Joliots this year) of artificial radioactivity.

Madame Curie was a modest woman and, as did her husband, always tried to keep away from the journalistic limelight. Like her husband, she also refused to accept the decoration of the Legion of Honor. Both Pierre and Marie Curie had their dreams in scientific work and in their little home. They walked, bicycled and did mountain climbing together in vacation. They worked together in the shed laboratory under severe hardships but with great results, making the science of radioactivity a reality and radium therapy an important branch of medicine. They never profited by their discoveries, having the true spirit of scientific investigation as their leading star. ALOIS F. KOVARIK.

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.

A Textbook of Organic Chemistry; by Joseph S. Chamberlain. Pp. xxv, 873; 17 tables. Philadelphia, 1934 (P. Blakiston's Son and Co., price $4.00).—This new edition of Prof. Chamberlain's well-known text does not differ in any essential respects from its predecessor. The main change has been to shorten the body of the text by nearly two hundred pages, the deleted material having been assembled at the end of the book in what is now a third section. This new section includes the chemistry of petroleum, industrial sugar, cellulose, amino acids, proteins, coal tar, diazo compounds, dyes, terpenes, uric acid, and the alkaloids. It is felt by the reviewer that this is a marked improvement in the book, as it was formerly much too long, and contained too much advanced material for the ordinary first-year course in Organic Chemistry.

Other minor changes have been made in the book, inculcating the more recent ideas in regard to modern electronic theories, and revising sugar structures in keeping with the latest advances. Formulas have been used generously, which is a great help to the elementary student. As previously, there is a list of questions and problems at the end of each chapter. ROBERT D. COGHILL.

Organic Chemistry. Vol. I, Chemistry of the Aliphatic Series; by Victor von Richter. Translated and revised from the 12th German edition by Eric Newmarch Allott. Third edition. Pp. xiv, 790; 14 figs. Philadelphia, 1934 (P. Blakiston's Son and Co., Inc., $10.00).—Certainly for a comprehensive text on Organic Chemistry, written in the English language, one cannot find any to approach in usefulness that of Professor Richter. It is very readable, both in regard to style, in so far as an Organic Chemistry can have style, and also in the actual physical appearance of the printed pages.

This latest edition, following five previous editions in the English language, has been brought up to date and many new references added. It has also been gone over and a large portion of the original references to "Centralblatt" replaced by references to the original articles. The 89 pages of Introduction preserve the order of the original German text, covering many subjects of a general nature. In addition two new sections have been added, one on Parachor and one on the Electronic Conception of Valency. It is needless to praise this book, its merits being well known to all Organic Chemists. It is a point of gratification to all that it is being kept available and up-to-date. ROBERT D. COGHILL.

Composition-Temperature Phase Equilibrium Diagrams of the Refractory Oxides; by ROBERT B. SOSMAN and OLAF ANDERSEN. Published by the Research Laboratory, U. S. Steel Corporation, Kearny, N. J. Price $2.00 per set of four sheets.—The four three-component systems derived from the oxides SiO_2, Al_2O_3, MgO and CaO yield an extraordinary number of compounds and solid solutions, which have been the subject of extensive investigations for many years, chiefly by the staff of the Geophysical Laboratory. Many, perhaps most, of the results have been published in this Journal. The quantitative data on these systems have now been assembled and published in the form of accurate triangular diagrams, one for each of the four systems. The diagrams enable one to follow accurately and quantitatively the processes of crystallization which occur when any fused mixture containing any three of the four oxides is allowed to cool to complete crystallization. The use of four colors in the diagrams greatly simplifies them. The four oxides mentioned above are the major constituents of silicate rocks, refractories and cements; the information contained in the diagrams will hence be of great interest and use to workers in these fields as well as to others. Both authors have contributed largely to the original data in this difficult field of high temperature phase equilibrium.

H. W. FOOTE.

GEOLOGY.

Grundzüge der Geologie und Lagerstättenkunde Chiles; by J. BRÜGGEN. Pp. vii, 362; 3 pls., 70 figs. and maps. Heidelberger Akad. Wissenschaften, Math.-Nat. Klasse. 1934.—This very readable volume gives succinctly the fundamental features of the geology and mineral resources of Chile. It has the great merit of having been written by one familiar with the language of the country, with the geologic literature, and with the field facts from long extended work in Chile.

Chile is manifestly a country of extraordinary geologic interest. The main Andine folding occurred in mid-Cretaceous time and was followed by the intrusion of the enormous Patagonian batholith, which extends from Cape Horn to the middle of Chile and probably into northern Chile, a distance of more than 2000 miles. It brought in the main metallic wealth of the country.

In mid-Tertiary, probably Miocene time, was formed the great rhyolite formation of northern Chile, which spreads into Bolivia and an unknown distance northward into Peru. The known area exceeds 110,000 square kilometers, and the rhyolite thus ranks with some of the world's great basalt eruptions. Chile is rich in volcanoes: there are more than a hundred active volcanoes and a thousand or so that are extinct. The seismic features are described, and the Pleistocene Ice Age is discussed in interesting

and valuable fashion. Two epochs (Riss and Würm) are recognized, and the stand is taken that the ice advances and retreats, although broadly contemporaneous with those of the Northern Hemisphere, were not absolutely synchronous.

More than a third of the volume is given to the description of the mineral resources and their origin. The most valuable of these resources are nitrates, copper, and silver. The reserves of nitrates are estimated to be 200 million metric tons, sufficient at the present rate of extraction, of 2 million tons a year, to last 100 years. ADOLPH KNOPF.

A Quaternary Stromatolitic Limestone from Bohuslän, Sweden; by A. H. WESTERGÅRD. Sver. Geol. Unders., ser. C, no. 381 (Årsbok 28, no. 1), 48 pp., 13 pls., 1934 (in Swedish, with English summary).—The chief interest of this paper is the discovery, so far north as Sweden and Norway, of thick *Cryptozoon*-like limestones of late Pleistocene age, which probably were formed "not far from the ice-margin." These limestones are at least 5 m. thick, and include some pollen grains but no other fossils. This is in keeping with most of our late Cambrian and early Ordovician *Cryptozoon* formations, which have no associated fossils. Evidently these Swedish limestones were formed in a shallow cold-water sea at 58° N. Lat. This is a rather surprising result, since most of the American *Cryptozoon* growths are believed to have been formed in warm and very shallow waters. The plates in the paper illustrate well the growth and appearance of these Swedish algoid masses. C. S.

Geologic History at a Glance; compiled by L. W. RICHARDS and G. L. RICHARDS, JR. 2 pp.; 2 pls. Stanford University Press (Educational, 80 cents; trade, $1.25).—An ingenious digest of the geologic history of North America consisting of two very large plates showing a composite geologic column with short descriptive text. Selected parts of the column are illustrated with combination photographs and block diagrams. The illustrations are drawn from Utah, Arizona, and California, and therefore should have special appeal for students in the western part of the United States. The column, however, applies to the entire continent, and includes a surprising quantity of information. R. F. F.

Dip and Strike Problems, Mathematically Surveyed; by KENNETH W. EARLE. Pp. x, 126; 122 figs. and folded plate. London, 1934 (Thomas Murby & Co., 12/6).—Problems involving various values of dip, strike, slope, thickness, pitch, hade, displacement, and so forth, in various combinations with one another, are solved mathematically and graphically. The author, feeling that graphical solutions are insufficient approximations, has gathered these together from the scattered literature, and supplemented them with his own trigonometric solutions. Evidently he

has lost sight of the fact that a trigonometric solution of a geologic structure must assume a geometrical regularity that seldom exists, and can less often be demonstrated. Other features of the book, such as the glossary, betray a considerable misconception of things geological. The value of the book lies chiefly in the bibliography and in the collection of graphical solutions; unfortunately for the latter, the author's style renders some of them difficult to understand. DAVID GALLAGHER.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

The Hilger Vitameter A. ADAM HILGER, 98 King's Rd., Camden Rd., London, N. W. 1. Publication No. 151/5.—This booklet describes the latest all-metal model for determining the Vitamin A content of cod and other fish-liver oils and concentrates. It is based on the spectrophotometric method of test. Measurements are made visually by comparing the intensity of two fluorescent areas and rendering them equal by a photometric device whose scale gives readings that are a direct measure of the Vitamin A content. A modified form has been designed for the estimation of Vitamin C.

The Endless Quest: 3,000 Years of Science; by F. W. WESTAWAY. Pp. xx, 1080; 51 pls. (3 colored), 193 cuts and diagrams. London, 1934 (Blakie and Son, 21s.).—This is an admirable compendium of science, which combines a history of the development of the different branches with a description and explanation of the most recent knowledge. The author studied under Huxley and has long been a teacher of chemistry and physics—a skilful and thorough teacher, as several passages in the book indicate. Any scientist who wants to have at hand a reliable summary of what has been done and is now thought in other fields than his own will find this book a handy manual of reference. In places it would be rather stiff reading for an ordinary American undergraduate, but he is unlikely to find any other book that will tell him more simply and entertainingly about the arduous explorations of nature and the most recent discoveries and theories.

The author has convictions of his own about controversial matters and does not avoid the expression of them, but he presents both sides by giving quotations from the best authorities. His discussion of mathematical physics shows a distrust for the extent to which Eddington and Jeans rely on a mathematical interpretation of the universe; he makes fun of indeterminacy and supports his argument against Eddington by quotations from Samuel, Dingle, Levy, Russell, and others. The vexed question of Lamarckian vs. Darwinian evolution is handled discerningly. Full credit is given to T. C. Chamberlin for the tidal hypothesis of the

origin of the planets, though Jeans and Jeffreys have pointedly omitted all reference to him.

Psychology and economics are not conceded to be sciences. Otherwise the book is all-embracing and furnishes information about topics that range from Aristotle's zoology through Faraday's humble salary to anthropology and the nature of hypothesis.

HENSHAW WARD.

Biologie der Fortpflanzung im Tierreich; von ULRICH GERHARDT. Pp. ix, 149; 47 figs. Berlin, 1934 (Julius Springer, RM. 4.80).—This little volume, the twenty-second in the "Verständliche Wissenschaft" series, describes in popular language, and also illustrates, many of the marvelous adaptations of animals for insuring the perpetuation of the species. It is an excellent summary of the various types of sexual differentiation, sexual instincts and behavior, maternal and paternal provisions for the protection and nourishment of the young and the modifications of the reproductive processes in lower and higher animals. W. R. C.

Elements of Modern Biology; by CHARLES ROBERT PLUNKETT. Pp. vii, 540; 166 figs. New York, 1934 (Henry Holt and Company, price $3.00).—This is a somewhat abbreviated and simplified revision of the author's *Outlines of Modern Biology*, and is now suitable for students who have not studied chemistry. It naturally emphasizes the physiological processes of organisms, the titles of the five chapters being: protoplasm, nutrition, response, reproduction, evolution. A knowledge of the activities and capacities of the living machines is found to be of greater value and more lasting interest to the average student than learning details of their structures. The subjects are so well chosen and so clearly presented that the reader should have no difficulty in acquiring a broad conception of the vital processes and the interrelations of living things. W. R. C

The Naturalist on the Prowl; by FRANCES PITT. Pp. x, 137; 31 plates. New York, 1934 (The Macmillan Company, $2.00).—This beautifully illustrated volume aims to show the novice "how to see, watch, study and photograph wild birds and beasts." But it is also an admirable illustration of the way in which an enthusiastic nature lover can obtain glimpses into the intimate family lives of shy, wild creatures and record those observations in a manner both instructive and fascinating. Anyone who can read these chapters without a longing to get out into the woods and fields is deserving of pity. The photographic plates, which are obviously the reward of infinite patience and great skill, are unexcelled. W. R. C.

OBITUARIES.

DR. ELMER ELLSWORTH BROWN, U. S. commissioner of education 1906-1911, chancellor of New York University 1911-1933, died on November 3 at the age of seventy-three.

DR. GILMAN ARTHUR DREW, professor of biology at the University of Maine from 1900 to 1911, and assistant director of the Woods Hole Biological Laboratory from 1911 to 1926, died recently in his sixty-sixth year.

DR. OTTO FOLIN, professor of biological chemistry in the Harvard Medical School, died on October 26 at the age of sixty-seven.

DR. JOSEPH FRANK MCGREGORY, head of the chemistry department at Colgate University from 1883 to 1929, died on October 14 at the age of seventy-nine.

DR. SAMUEL PARSONS, professor of organic chemistry at the Massachusetts Institute of Technology, died on October 24 in his seventieth year.

DR. EDWARD RENOUF, professor of chemistry at the Johns Hopkins University for twenty-five years, died on November 13 at the age of eighty-eight.

SIR ARTHUR SCHUSTER was professor of physics at the University of Manchester from 1888 to 1907; also secretary of the Royal Society, and from 1919 secretary of the International Research Council. He died on October 14 at the age of eighty-three.

PUBLICATIONS RECENTLY RECEIVED.

Egyptian Government. Ministry of Public Works. Annual Reports for the Years 1924-1925 and 1925-1926, Pts. I and II. Price each part P. T. 20. (Publications Office, Government Press, Bulaq, Cairo.)

From Galileo to Cosmic Rays; by Harvey B. Lemon. Chicago, 1934 (University of Chicago Press, Education Edition $3.75, Stereoscope 75 cents (extra); Trade Edition (with stereoscope) $5.00).

Paläohistologie der Pflanze; Elise Hofmann. Vienna, 1934 (Julius Springer, RM. 24, gebunden RM. 25.20).

A Laboratory Manual of Physical and Historical Geology; by Kirtley F. Mather and Chalmer J. Roy. New York, 1934 (D. Appleton-Century Co., $2.50).

Studies on Some Protozoan Parasites of Fishes of Illinois; by Richard R. Kudo. Urbana, 1934 (University of Illinois Press, 75 cents).

Historical Geology; Walter A. Ver Wiebe. First Edition. Ann Arbor, Mich., 1934 (Edwards Brothers).

Guide to the Geological Model of Ardnamurchan; by J. E. Richey. Edinburgh, 1934 (His Majesty's Stationery Office, 1s. net).

Animalium Cavernarum Catalogus; auctore B. Wolf. Pars I and II. Berlin, 1934 (W. Junk, Einzel-Preis M. 18, Subscriptions-Preis M, 13.50).

Einführung in die Lehre von den Kolloiden; herausgegeben von H. Bechhold. Dresden, 1934 (Verlagsbuchhandlung Theodor Steinkopff RM. 9, gebunden RM. 10).

Mitteilungen des Hoerbiger-Institute. Leitern typischer Grössen.

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